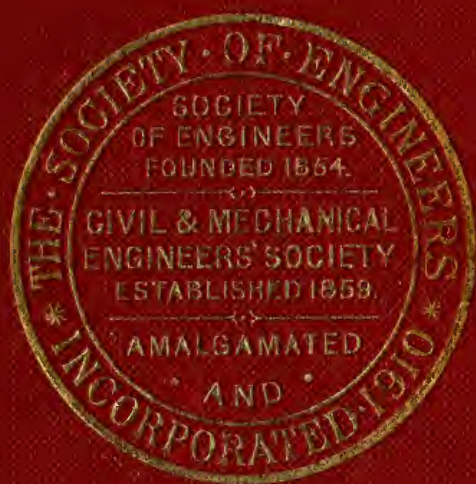
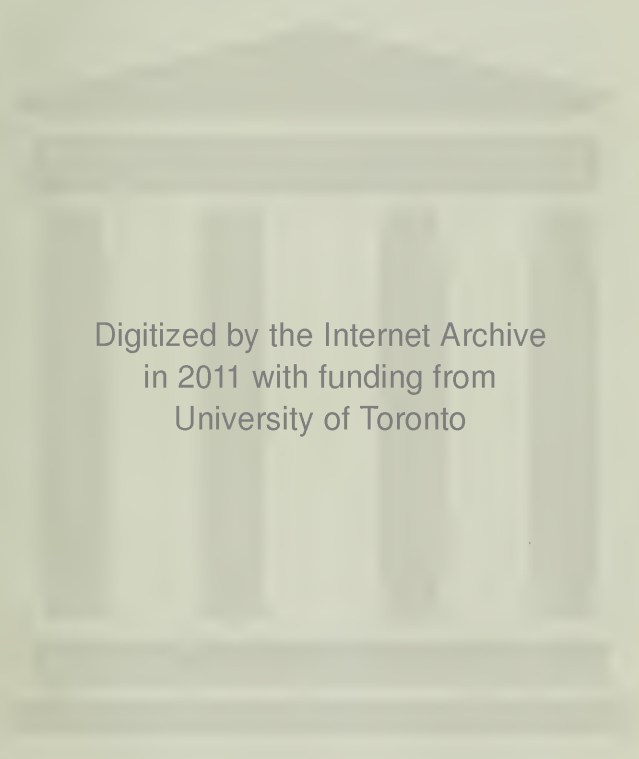






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[Lafayette.

JOHN KENNEDY,
President of The Society of Engineers (Incorporated) 1912.
(See page 5.)

(THE)
SOCIETY OF ENGINEERS

(INCORPORATED).

SOCIETY OF ENGINEERS: ESTABLISHED MAY, 1854

CIVIL & MECHANICAL ENGINEERS' SOCIETY: FOUNDED MAY, 1859

} AMALGAMATED AND
INCORPORATED 1910.

Journal and
TRANSACTIONS (FOR) 1912.

EDITED BY

A. S. E. ACKERMANN, B.SC.(ENGINEERING),

A.C.G.I., A.M.Inst.C.E., M.R.S.I.

SECRETARY.

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LONDON:

PUBLISHED BY THE SOCIETY OF ENGINEERS
(INCORPORATED),

17, VICTORIA STREET, WESTMINSTER, S.W.

1912.

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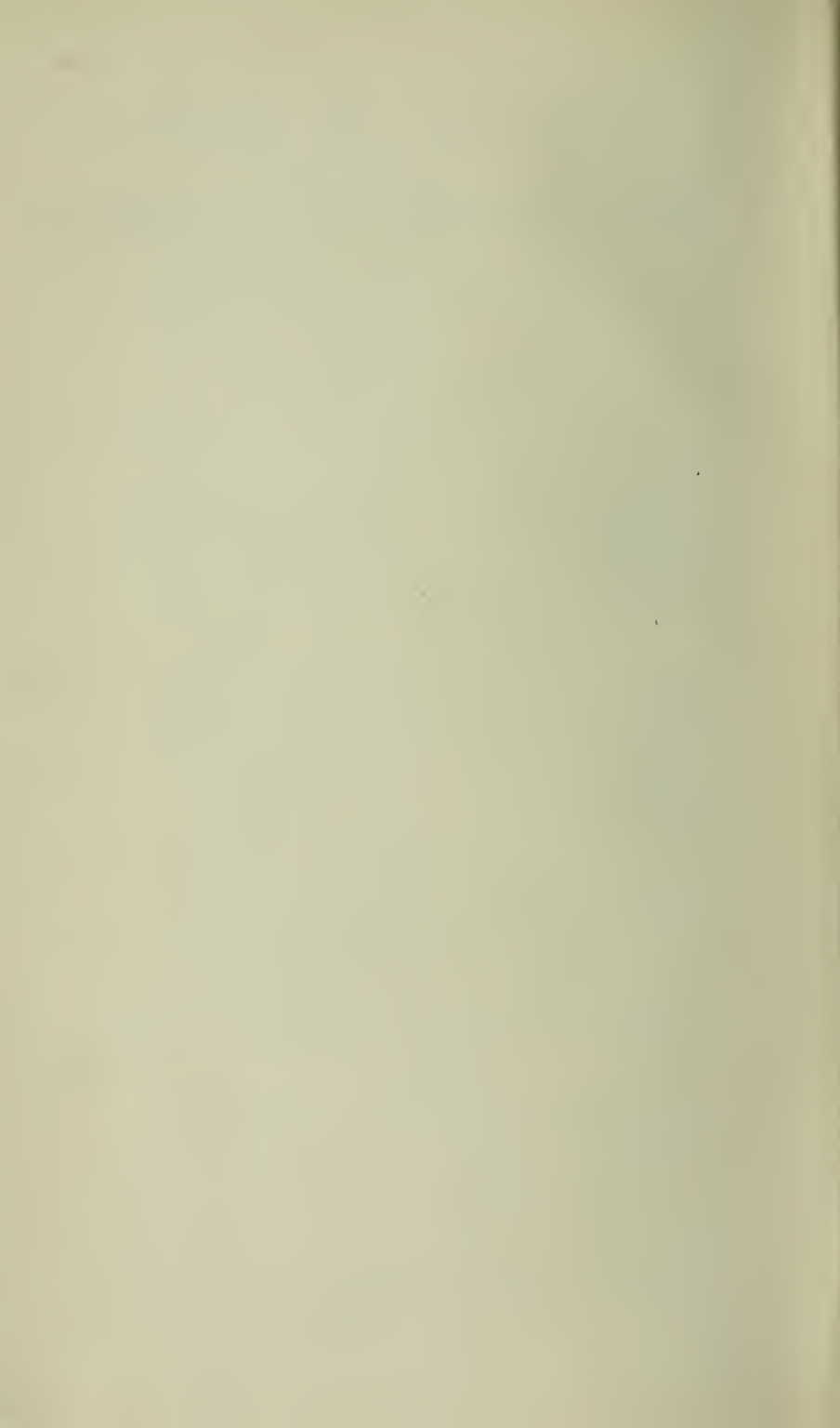
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JOHN KENNEDY,

PRESIDENT OF THE SOCIETY OF ENGINEERS (INCORPORATED)
FOR THE YEAR 1912.

MR. JOHN KENNEDY, whose portrait will be found at the beginning of this volume, was educated at Greenock Academy, being afterwards apprenticed to Messrs. MacNab and Clark, Marine Engineers, Greenock, and passing through all the shops. Soon afterwards he entered the service of Messrs. Robt. MacAndrew & Co., Shipowners and Merchants, as second engineer of their steamer *Velasquez*, being promoted to chief engineer nine months after. In 1872 he was appointed Superintendent and Consulting Engineer for the company, and is still in their service.

He is a member of the Institution of Engineers and Shipbuilders in Scotland and a Fellow of the Royal Geographical Society, and holds the chairmanship of the Glengall Iron Works and of the British Arc Welding Co.

Mr. Kennedy was elected as a member of the old Society of Engineers in 1876, and became a Fellow of the incorporated Society on its formation.

PAPERS AND PREMIUMS.

THE Council of The Society of Engineers invite original communications from members, as well as from gentlemen who do not belong to the Society, on subjects connected with any branch of Engineering.

For any papers published in the JOURNAL that may be considered sufficiently meritorious the Council may at their discretion award one or more of the following Premiums, viz. :—

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The number and value of the Society's Premiums are decided by the Council according to the number of meritorious papers published during the year.

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THE SUBTERRANEAN EROSION OF WATER-BEARING STRATA IN RELATION TO POLLUTION.

By SPENCER SILLS
(Member).

AMONG the engineering problems of the day the demand for a safe and efficient water supply—whether it be for a mansion, a village, an industrial undertaking, or a populous city—is of the greatest importance, and the time appears to be fast approaching when the whole of the country will be mapped out into carefully conserved water areas, with every available source marked for some particular and definite service.

In the light of our present knowledge we look back with disgust upon those conditions which but two generations ago were characteristic of many of our cities and towns, when shallow wells and surface springs afforded the sole supply; yet the smaller communities even now are for the greater part dependent upon such supplies. Moreover, the increasing intimacy between town and village, due to the ever-growing facilities for communication, makes isolation more and more uncommon, and ills which affect the village often spread their influence to the town in one form or another.

We are told that the present method or want of method in obtaining supplies of water is haphazard and uneconomical, and it certainly would appear that engineering practice in this direction is not altogether in line with the general scientific advancement. The future will demand schemes of a much more comprehensive character than the typical undertaking of to-day, which has for its aim the supply of some particular town or group of villages lying within a restricted area. Topographical features rather than the boundaries of municipalities or urban districts will define the limits of such supply, and the needs of the area dominated by such features will be the primary consideration. In fact, the question of water supplies is already beyond the parochial stage, and is fast becoming a matter of national concern.

The conflict of private interests with public needs will ever be a source of difficulties which the most careful legislation is unlikely to solve satisfactorily, nor is it probable, where dividends have to be considered, that Water Boards will adopt a tariff so satisfactory to large consumers that private wells will no longer be a necessity. Yet it is most desirable for the public weal that such private supplies should be limited as being un-

economical and often potential sources of contamination for subterranean sources of supply.

"Pure water" is a figure of speech often used by those who are well aware of its misapplication. All waters are tinctured with impurities to a lesser or greater degree—with mineral salts in solution obtained from the rocks over or through which they flow, and with gases absorbed from similar sources or from the air—and all have some traces of organic pollution in varying degree. Indeed, scientific opinion is greatly divided as to what is to be deemed a wholesome water; and where a given sample of the fluid may be unhesitatingly accepted as wholesome by one analyst, another equally skilled may discover in it grave cause for alarm.

Such being the case, it would appear that the wholesome character of a water is chiefly to be judged by its negative results. A broad definition of a wholesome water has been given as one which is odourless and palatable, and which does not convey disease germs or other harmful matters into the human system. Water is liable to harmful pollution not only at the source but during the process of storage, distribution, and even filtration, and the possibility of some trouble of this description is always present, let the source be what it may, inasmuch as the human factor has always to be taken into account.

Effective protection of the source under any circumstances is seldom a simple matter, and in regard to subterranean sources the difficulty is enhanced by the rights of the individual. A landowner has the right to use any water which may flow through or under his land, and where the water flows in a defined channel he is under obligation to return to the channel all the water except that which has been consumed by men and animals, and he is held responsible in some measure for any acts which may lead to the pollution of such stream; but in respect to underground water there is no such obligation, and the difficulties in the way of identifying such water make it hard to prove any specific act of pollution. A landlord may, therefore, turn a well to uses which are highly dangerous to neighbouring water supplies, and the users of that water have no power to restrain him. The frequency with which such acts are committed is a matter which demands serious attention in view of the rapidly increasing demands upon subterranean sources.

To the average landowner the use of an abandoned well as a cesspool is obviously a measure of economy, and the conversion is effected in utter ignorance of any likelihood of dangerous consequences to the community; and since he is at liberty to sink absorbing wells or cesspools in the same strata, he cannot perhaps be considered so unreasonable in thus utilising a well which is no longer needed for its original purpose. Even if the abandoned well is not so misused he is under no obligation to

protect that well from chance pollution by objectionable matter falling therein, and so long as the shaft is safe as regards physical injury to man, he has done all that the law requires.

The writer some time back enquired into the history of the private wells situated upon a watershed from which was drawn a large subterranean supply for public use. Of 26 wells marked upon the Ordnance Survey as existent in 1869, 13 were still open, but only 9 were used for domestic purposes, and 2 had been some time abandoned owing to the polluted condition of the water. Of the other thirteen, 2 were filled with dry rubble and earth, 3 were used as deposits for house refuse and garbage, 4 were converted into cesspools or absorbing wells for house drainage, and 1 was within a few feet of a cesspool; while the remaining 3 were covered in, but circumstances pointed to one at least, and probably all three, being used as cesspools. The foregoing were in all instances situated above the wells of the public supply, and were sunk deeply into pervious strata from which that supply was drawn.

It may be argued that after all the amount of pollution poured into the strata over a sparsely populated area 5 or 6 square miles in extent is so small in comparison with the vast amount of subterranean water with which it ultimately mixes, and the extent of rock through which it must travel before it can reach the public supply, that the chance of pollution is small, but in the instance referred to it was significant that some of the wells, distant $1\frac{1}{2}$ miles from a pumping station, had recently failed, and that one of the polluted private wells was some distance away from a cesspool or any similar source of pollution.

A water company as a rule purchases but very little more ground than will suffice for the establishment of its pumping station and reservoirs with a reasonable margin for future extension, and beyond and around this is land upon which the owner may dig wells and use them for any purpose that may suit his convenience, or lay out a building estate, the sewage from which may pollute the water supply. The purchase of upland gathering grounds is usually within the range of economic possibility, as much of such land has little value, but purchase is altogether out of the question where subterranean supplies are concerned, especially near towns or in other situations where land is expensive.

Primarily we depend for our water supplies upon the annual rainfall over a given area, and the quantity available for such purpose depends not only upon local meteorological conditions but also on the nature and disposition of the geological strata, the topographical features and the condition of cultivation, etc., of the area. The quality of the supply also influenced by geological conditions, natural features, and cultivation in a lesser degree.

Nature, when left to her own resources, carries out a complete purification of waters falling upon the surface as they filter through the soil and the subjacent rock, or flow along the watercourse, and chemically and bacteriologically the fluid is so dealt with that its wholesome character is assured, but the presence of Man, be his numbers ever so small, near the stream or gathering ground, is the disturbing influence which is responsible for all the difficulties appertaining to this subject, and it is some act of Man that is to be looked for when pollution of the spring arises. With subterranean waters, it is the top soil which deals most extensively and effectually with organic impurity, and although the subsequent percolation through the underlying rock may effect a certain degree of purification chemically, the fissured character of many of our water-bearing formations is such that there is a chance of polluted streams gaining a somewhat free access to subterranean springs where the rock is practically free of top soil.

The chalk formation, with which the writer is most familiar, forms one of the principal sources of water supply in the Kingdom. Kent is said to have the largest water supply in the world obtained solely from wells, and principally from the chalk, the wholesome character of water derived from this source probably standing higher than that of water obtained from any other formation. Chalk is described by Woodward as a "formation of soft and hard white limestone with and without flints and with occasional bands of marl." It extends over a large area and is generally of great thickness, varying in our south-eastern corner of the country from 600 to 800 feet. The formation is classed by geologists in three main divisions :—

1. The upper or white chalk, which is of a friable nature, and contains numerous small fissures and frequently occurring bands or beds of flint.

2. The middle chalk, which is more compact, is less freely fissured, has fewer flints and occasional interstratifications of a marly or clay-like character.

3. The lower or grey chalk, very hard and compact, with few or no fissures, no flints, and beds of marl of greater thickness.

The upper chalk forms much the greater part of the outcrop, and although in parts greatly thinned down by denudation it is of great thickness in other localities. The middle chalk appears in the escarpment of the North Downs and "probably," says Whitaker, "occurs at the surface some way down the main valleys which breach that escarpment." The lower chalk has a very limited outcrop, principally on the lower slopes of the North Downs, and occasionally along the bottom of the greater valleys.

Of the Kentish chalk area, 43% is bare chalk covered very thinly with soil; 8 % is overlaid by permeable beds of drift gravel and sand through which the water readily finds its way to the chalk; 37% is covered by mixed beds of varying character in which clay-like strata retard percolation; and the remaining 12% is covered with impermeable strata which drain the water away from the chalk or conduct it to the edge of the formation where it enters the chalk.*

The chalk absorbs water readily, but parts with it very slowly—that is to say, there is no freedom of percolation through the mass of chalk, but it is by way of numerous cracks and fissures that the water passes through the formation. A certain amount flows along the bedding planes, but the greater quantity by far makes its way through the vertical jointing that is characteristic of limestone formations.

The joint planes generally occur in a dominant direction, but cross joints facilitate the flow and act as feeders to the flow along the main jointing. Thus we have a somewhat free flow both vertically and horizontally, and although the fissures as a rule are mere cracks varying from $\frac{1}{4}$ inch to 2 inches in width, their frequent occurrence, particularly in the upper chalk, makes the storage capacity of the rock very great. The upper and middle chalk form the great storage, the lower chalk, owing to the scarcity of fissures, yielding little or no water.

Subterranean water is seldom to be found in a quiescent state except where held in a cup or basin of impermeable strata, and a constant flow obtains toward points of issue at greater or lesser depth below the saturation line. This underground drainage of the chalk is said to follow and to agree fairly closely with the surface configuration, and subterranean streams follow much the same course as would streams flowing upon the surface of the formation. Although the fissures of the chalk are commonly so small, occasionally very much larger fissures are discovered, and there is reason to believe that in the deeper zones the occurrence of extensive cavities may be more common than is generally supposed.

In most limestone formations water-worn passages and caverns are not uncommon, and underground streams of some magnitude are known to exist, but the chalk is usually thought to be an exception in this respect. The general uniformity in the rock texture and the fissured condition of the upper strata, which allows of such free percolation, would account for this belief, but at greater depths where the rock is not so uniform the existence of such cavities is probably common. This probability is heightened by the frequent occurrence of swallow holes, which are also characteristic features of other limestone formations where extensive underground streams are of usual occurrence.

* Whitaker's "Water Supply of Kent."

These holes are formed by streams which rise in the higher ground and flow over impermeable strata until they reach the chalk or some overlying pervious beds, into which they sink.

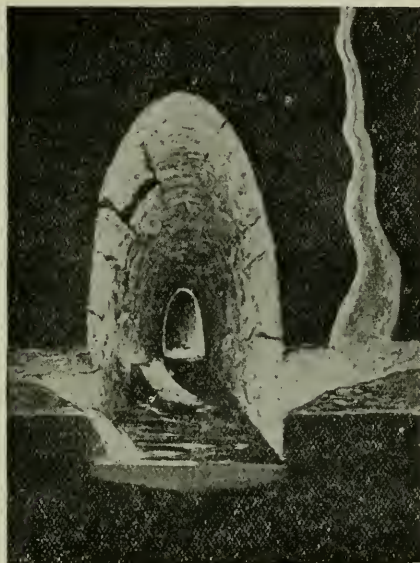
The combined chemical action and mechanical force of the water forms in the course of time funnel-shaped basins, often of large extent, into which the stream disappears, and although the streams discharging into these holes are said to be generally insignificant, occasionally, as in times of heavy rainfall, large quantities of rainfall must be carried by this means into the rock. This would point to a much greater freedom of flow than is usually conceded.

A group of seven swallow holes into which six or seven small streams disappear, is said to exist near Canterbury, within a range of one mile, and Mr. Whitaker says that a large spring issuing into the River Stour is attributed to streams which lose themselves in swallow holes a mile away. Some such holes in that neighbourhood were found to measure 30 to 40 feet across and 20 to 30 feet deep, and still more remarkable ones are noted by Prestwich as being 80 feet deep.

The erosive action of underground waters has received particular attention from Mr. F. J. Bennett, F.G.S., with whom the writer has had an opportunity of discussing his theory of the "Solution Subsidence of Valleys." Mr. Bennett's theory is that the hydrostatic action of subterranean streams has been in many instances largely responsible for the formation of swallow holes by the upward wasting of the rock at its weakest points. Thus, following the line of a pre-existing fissure, a series of these holes has been carved out from below. Subsequently, surface streams cut through the thinned crust into these holes, and the shafts thus formed in course of time broke one into the other, forming a ravine, which was ultimately softened off by further erosion into a valley. Abundant evidence in support of his theory is brought forward by Mr. Bennett in the curious features noticeable in the valleys of the Hythe beds of the green-sand formation at Malling, and in the neighbourhood of Maidstone, and he further suggests that many of the dry valleys of the chalk have been similarly formed.

Artesian conditions, he imagines, may have been induced during the glacial epoch by a frozen soil-cap, which served the purpose of an impervious stratum, covering the water-bearing rock. Some slight evidence of such conditions lies perhaps in the curious trumpet-shaped fissures which the writer has noticed in the chalk. One of these, at Luton, Chatham, is described by Mr. Finch, the Resident Engineer to the Water Company. This was discovered at a depth of 150 feet and extended upward from the roof of a dry water-course in spiral form. The dry water-worn passage was 3 or 4 feet wide and about the same height, and a man could stand erect with ease in the

mouth of the vertical fissure, and by holding a candle above his head could trace the course of the fissure for 30 feet or more towards the surface.



CHALK FISSURE AT LUTON (CHATHAM).

Caverns in the chalk have seldom been noted in the ordinary course of well-sinking. Sir Joseph Prestwich certainly mentions one which was found at Knockholt, near Sevenoaks, at a depth of 270 feet, but we know but little of this except that it was 30 feet long, 12 feet wide and 18 feet high, and had a stream of water running through it.

The solvent action of rain acidulated by its contact with the air and surface vegetation is so great that Sir John Evans has calculated that a square mile of chalk in the Thames basin loses 140 tons per year, which is carried off as lime-carbonate by that river. This is not an extravagant estimate and does not take into account the vast amount of detritus which must be carried in suspension by strongly issuing streams. Chalk water containing 16 grains of lime-carbonate per gallon is not at all uncommon, and 1,000,000 gallons of such water removes from the sides of cracks and fissures 1.23 tons of the rock. By this agency alone a considerable amount of subterranean denudation is accomplished without the mere mechanical erosion, which must be very great with a vigorous flow.

A more comprehensive idea of the extent of such action may be gained by the study of the remarkable underground conditions

at Rochester, with which the writer is intimately acquainted. The waterworks, which have been in existence since 1849, had four pump wells sunk at various periods, the earlier sinkings reaching a depth of 113 feet and the later wells 120 feet, or 10 below o.d. There is the usual system of adits connecting the wells, which affords some storage capacity. The extension of the workings from time to time has been generally westerly, but there appears to have been some hesitation in the minds of the early undertakers as to the direction which it would be most profitable to pursue. In this manner the workers stumbled upon a source of supply which has proved to be sufficient for the needs of the neighbourhood since its discovery in 1879. During the operations carried out at the above date the workmen engaged in driving an adit encountered a hard wall of chalk which was with much difficulty broken through, disclosing a considerable cavern through which the water flowed copiously. Further work in this direction was suspended until 1888, when the cavern was cleared of the chalk debris, about 200 tons, and the full extent of the chamber exposed. It was then seen that the streams of water flowed into the cavern from the western end. Additional works, which included a new well and adit, revealed a length of natural adit extending about 30 feet west from the cavern, at the end of which the spring flowed out from what appeared to be a large hole partially filled with sand and clay (See Plan No. I.).

In 1903 the writer was introduced to the situation upon the occasion of further extensions necessitated by a shortage of water. At that time there was a total length of about 300 feet of adits, but those to the North and East were practically barren while the western adit yielded numbers of tiny springs which bubbled up through the floor and spouted from the walls, in addition to the larger spring which flowed steadily from the end. Operations were commenced by deepening the well and the cross adit furthest west, and driving a connecting adit to the adjoining well. The work of deepening had not proceeded far before trouble arose from the large quantities of fine sand washed down from the natural adit, and it was found expedient to place timber dams across the deepened passage, forming a series of settling pools to avoid the choking of the pumps, while an attempt was made to deal with the clay and sand which appeared to choke the fissure from which the stream issued. This proved to be, however, a work of greater magnitude than was at first imagined, and day by day the fissure widened and deepened until the one-time crevice became a passage of surprising proportions extending to an unknown distance.

The silt consisted of fine sand and clay with small quantities of water-worn pebbles and angular pieces of flint. The passage was so far cleared, to a point 105 feet from the cross adit, that



FIG. 1.—VIEW OF ADIT AT ROCHESTER, SHEWING ACCUMULATION OF SILT.



FIG. 2. — VIEW OF ADIT PARTIALLY CLEARED.



FIG. 3.—VIEW FROM SAME POINT AS FIG. 2, SHEWING ADIT CLEARED.



FIG. 4.—GENERAL VIEW OF ADIT FROM CAVERN.

the remaining silt assumed an angle of repose, the scour upon the channel floor being largely checked by a block of chalk which lay completely across the passage at this point, and over which the spring welled up from the unexplored regions beyond. The passage thus far revealed measured from 4 to 5 feet in width and 4 feet to $5\frac{1}{2}$ feet in height, having a general direction west by north-west. Beyond the point last mentioned where the work of clearing ceased, the passage, as far as could be judged, continued of much the same size and form. The sides of the adit were in places much stained with iron from the silt washed down from the overlying beds, and here and there were so deeply undercut that occasional trimming was necessary to avoid untimely falls.

A remarkable feature is the enlargement of the adit at points varying roughly from 30 to 40 feet distant from one another. These enlargements extend laterally and vertically and seem to occur at each change of direction in the course. In some cases a fissure traverses the enlargement and probably provided at one time a tributary stream, which would account for some additional fretting away of the chalk, but in other cases there is no such evidence and the enlargement was caused, perhaps, by the temporary obstruction of the stream by a fallen block of chalk, such as lies at the end of the explored portion.

From numerous small fissures along the walls lively little streams issued as the silt was removed, but as the work proceeded these ceased to flow, as the main stream obtained a less obstructed vent. The arched form of the adit roof along the main passage, as seen in the illustrations, is quite natural, and remains untouched by a tool of any description throughout the entire length, except at one or two places in the large chamber where the chalk was much crushed and splintered and had to be trimmed of loose and unstable matter. The adit generally retains its original form save where shown to be deepened (see Section) and one or two places where it was deemed advisable to cut away, as mentioned above.

Two or three funnel-shaped pipes appear in the roof, similar to that noted at Luton (Chatham). The most remarkable of these occurs in the large chamber, and the writer's attempt to gauge the extent of this with a pole resulted in an avalanche of stones of such formidable proportions that his curious enquiries were quickly abandoned.

From the western end of the adit the roof ascends gradually until reaching the cavern, when it rises abruptly to 13 feet and then sharply to $17\frac{1}{2}$ feet. This and the abrupt change of direction in the passage is due to a slight fault or up-throw of the chalk, which strikes across the workings from north to south, and to an impermeable and rock-like mass of chalk which lies along the side of this fault, and which originally formed an

effectual barrier to the passage of the stream in an easterly direction. (See Plan II.). The chamber or cavern is roughly Z-shaped on plan, the western arm being about 28 feet long by 10 feet wide, the stem 18 feet long by 9 feet wide, and the eastern arm 18 feet by 10 feet. The height throughout varies from 9 feet to $17\frac{1}{2}$ feet. At the end of the eastern arm several large fissures, now bricked up, suggest the one-time exit of the stream toward the river, which lies south-east from this point.

The demand upon this supply for public needs is about 277,000 gallons per day, and this is raised at the rate of 63,000 gallons per hour. Previous to the commencement of the work in 1903 the shortage was so pronounced that the quantity had to be pumped in short spells with intervals of rest to allow the springs to recover. On one such occasion six pumpings were necessary for the day—the total time pumping amounting to $8\frac{3}{4}$ hours. Upon the completion of the work a trial of ten hours continuous pumping was carried out, the yield throughout the ten hours being 72,000 gallons per hour, and during this trial the water level was lowered 7 feet. When pumping ceased the rise was carefully gauged until the rest level was reached after a period of 8 hours.

The stream appears, originally, to have made its way over a particularly compact and well defined stratum of tabular flint which still formed a floor to the adit and could be traced for the greater part of the length explored. This flint layer had a somewhat sharp inclination, about 1 in 30 from west to east or in the direction of the stream flow, and the general inclination of the adit floor from the limit of exploration to the centre of the cavern averaged 1 in 21. Rest water level is about 12 feet above this latter point and 18 feet above the adit floor at its furthest end. The volume of water passing in this direction would probably be greatly increased by further clearing of the adit, as other outlets may possibly exist at slightly higher levels than those mentioned above, which once served that purpose.

It is obviously as possible for such a stream as for one flowing at the surface to become polluted in the circumstances given above, but where the latter would in all probability betray by visible signs the fact of its pollution the same danger signals would often be lacking in the former case, owing to the filtering out of matter in suspension that would otherwise awaken suspicion. Again, the active subterranean erosion may after a time open up polluted fissures, or continued or excessive pumping may make demands upon strata which are receiving human or animal sewage in large quantities, by way of cesspools, or disused wells so used. Dr. Thresh quotes an instance of a well 294 feet deep, which was polluted by the discharge of sewage into a disused quarry 800 feet away, and given suitable conditions it is possible

for such impurities to travel much greater distances in the chalk.

Deep-seated chalk waters contain as a rule a larger amount of saline matter than water obtained nearer the surface, and the presence of a comparatively large amount of common salt does not necessarily point to sewage pollution. This has been accounted for by the theory that the lower strata still contain a certain proportion of this salt, due to the marine origin of the formation; that in the upper strata having been removed by the washing of the rainfall. But in a great many instances there is reason to believe that even at great distances from the coast or tidal waters there is a passage of a certain amount of saline matter by way of extensive subaqueous fissures into the strata. Point is given to this by the fact that a very great amount of chalk water finds vent in submarine springs.

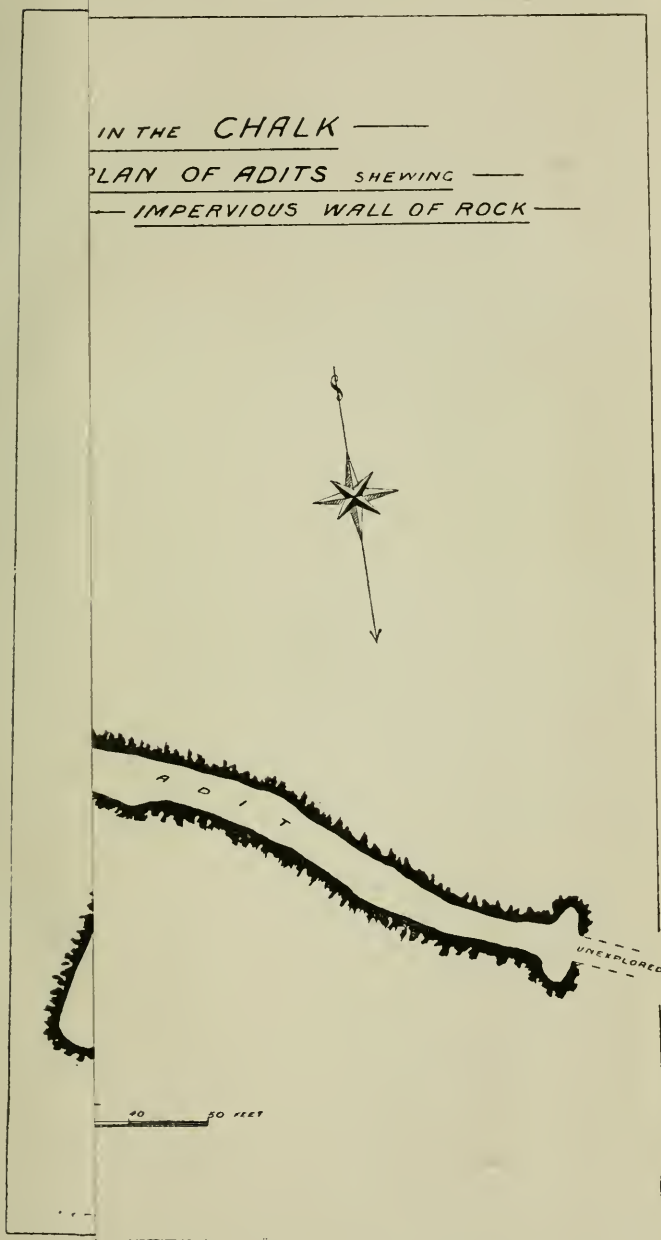
Several chalk springs have been noticed by the writer in the bed of the Medway, which is tidal for some miles above their points of issue, and one particularly deep hole in the river bed marks the outlet of a very strong spring, which according to tradition used to be very much stronger. This, curiously enough, is in such a position that it may have been the one-time outlet from the natural adit referred to above. Quoting again from Dr. Thresh, a chalk well during a particularly dry season became perceptibly diluted with sea water although the coast was $1\frac{1}{2}$ miles away.

The writer has no wish to pose as an alarmist, and he is probably pointing out much that is matter of common knowledge, but it has often occurred to him that too little is known, by those responsible for the control of public supplies, of the source from which subterranean waters are drawn. So long as the yield is abundant and the periodical analyses show no marked depreciation of quality, the general satisfaction is undisturbed, and so far there may have been little need to worry further. It must, however, be borne in mind that year by year the demand is rapidly increasing, and as the underground reservoirs are drawn upon for greater and still greater volumes, joints and fissures are opened up which, while further increasing the storage capacity of the rock, at the same time facilitate a less restrained and more rapid passage of the water from point to point.

An intimate knowledge of the catchment area of every supply should be deemed an essential item in the administration equipment. Its probable boundaries, the approximate depth and disposition of the water-bearing rock, the character and thickness of the overlying beds, and the trend of underground and water surface features should be known, while artificial conditions, such as particulars of cultivation, the position of farmsteads and human habitations and particularly the means

of water supply and the methods employed for the disposal of sewage from such establishments, should also be noted. Positions and full particulars of all wells should be carefully scheduled as well as the depth to which they are sunk, the strata through which they pass, the character of the water they yield and their relative water levels. Data such as this are likely to prove of the greatest service, and at the least the knowledge may afford an opportunity of tendering advice and offering assistance to landowners on the area, in circumstances which may sometimes mean the abandonment of a practice tending to imperil the safety of the supply.

TO POLLUTION. By SPENCER SILLS.

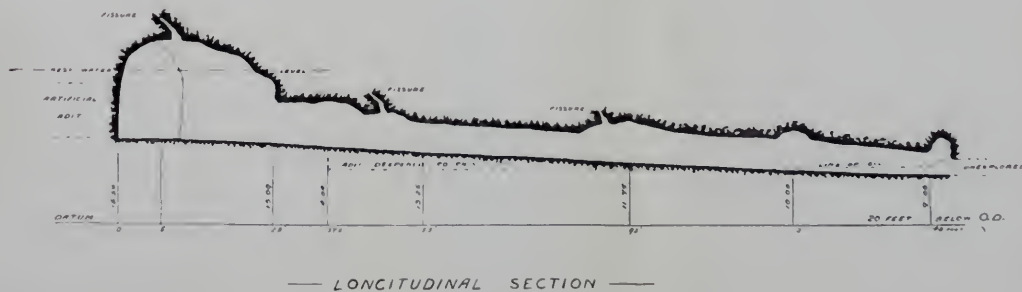


PLAN
OF THE SOCIETY OF ENGINEERS (INCORPORATED),
January, 1912.

IN THE CHALK ———
AT ROCHESTER ———



— NATURAL ADIT IN THE CHALK —
— AT ROCHESTER —



SCALE OF FEET
0 10 20 30

5th February, 1912.

ORDINARY MEETING.

Mr. F. G. BLOYD (Past President) in the Chair.

The minutes of the previous meeting were read and confirmed.

The names of candidates proposed for election were announced by the Secretary.

The Chairman then presented the following premiums awarded for papers published in the JOURNAL during 1911 :—

The President's Gold Medal to Mr. W. R. Baldwin-Wiseman for his paper on "The Administrative Aspect of Water Conservancy."

The Bessemer Premium, value £5 5s., to Mr. R. W. A. Brewer for his paper on "Two-Stroke Cycle Engines."

The Clarke Premium, value £5 5s., to Mr. T. J. Gueritte for his paper on "The Mechanical Installation and Upkeep of Permanent Way on Railways."

A Society's Premium, value £3 3s., to Mr. E. Kilburn Scott for his paper on "Nitrogen Products made with the Aid of Electric Power."

A Society's Premium, value £3 3s., to Mr. F. G. Woollard for his paper, entitled, "Some Notes on Drawing Office Organisation."

Mr. R. W. A. Brewer, returning thanks for the Bessemer Premium, said that some explanation might be given as to the form which he had decided that the premium should take, namely, a watch. In the branch of the profession to which he belonged the question of units was most important, and, knowing the views of their esteemed Secretary upon the definition of units, particularly in the preparation of a paper, he had decided that some instrument connected with units would constitute a most fitting form for the prize to take. The work which he had the pleasure to carry out was most cosmopolitan, and, fortunately, the linear units with which he was most familiar were in the metric system. There was only one unit of which he was aware which was universal in all civilised countries, and that was the unit of time. This unit was not an arbitrary one, subject to the caprice of any human ruling body. He had therefore chosen an instrument of precision, the daily use of which would remind him of the fact that the unit which it registered was only half as long as he would wish ; and, further, every time he used the watch he

would be reminded of the Society, which the members so much esteemed and the welfare of which they all had at heart. He wished the Society every success in the coming year.

The other recipients of premiums also made due acknowledgment of the presentations.

The **Chairman** said that, in addition to thanking those to whom he had presented premiums, the Society wished to express its thanks to Professor Henry Adams, Mr. H. Conradi, Mr. C. R. Enock, Mr. E. Scott-Snell, and Mr. H. C. H. Shenton for papers which they had contributed during 1911. Three of the gentlemen whom he had mentioned, namely, Professor Adams, Mr. Scott-Snell, and Mr. Shenton, being members of the Council, were not eligible for premiums. He thought that for this reason the Society was all the more indebted to them for kindly coming forward and contributing papers.

INDUCTION OF THE PRESIDENT.

The **Chairman**, continuing, said that it was now his pleasure to introduce Mr. Kennedy as President for the coming year. He was sure that he need not ask the members to give to Mr. Kennedy the hearty support which the Council, the officers, and the members generally had accorded to himself. They all wished Mr. Kennedy a very happy and prosperous year of office.

The retiring President then invested Mr. Kennedy with the Presidential badge and handed him his certificate of election, after which the new President took the chair.

The **President** said that he had very much pleasure in proposing a vote of thanks to the retiring President, Mr. Bloyd. During his year of office Mr. Bloyd had unfortunately had very severe illness in his family, which had necessitated his absence from many of the meetings. The members were glad to know that all danger was now past, and they hoped that Mrs. Bloyd would make a very speedy and a permanent recovery.

Mr. W. Noble Twelvetrees said that it was with very great pleasure that he seconded the vote of thanks which had been so ably proposed by the President. He used the word "ably" quite advisedly, because he believed that the best way to propose a vote of thanks such as the present one was to do it in the very smallest number of words possible. Therefore he proposed to follow strictly the lead set by their worthy President.

The vote of thanks was very cordially passed.

Mr. F. G. Bloyd thanked the meeting very much for the kind way in which they had viewed the small amount of work which he had done for the Society during the past year. Per-

sonally, he was very sorry that he had been kept away from some of the meetings ; but he was fortified by the knowledge of the fact that he would be an *ex officio* member of the Council for the next three or four years, and he promised the members that he would do his best to make amends. His year of office had been an extremely happy and pleasant one. His thanks were due to the Council and to the members generally for the kind way in which they had always supported him. He did not think that it would be fitting for him to close his remarks without thanking the officers of the Society. No society could do really good work, and the President could not do very much, without able backing up by the officers. As to Mr. D. B. Butler, the Honorary Secretary and Treasurer, and Mr. Ackermann and his staff, he could only say that he thanked them very much for the kind way in which they had always assisted him. He should always look back to the past year as being one of the happiest years of his life. He felt sure that he need not ask for the same kind aid to Mr. Kennedy and his successors.

Mr. John Kennedy, the **President** for the year 1912, then delivered his

PRESIDENTIAL ADDRESS.

I RISE with feelings of deep gratitude to the members of this Society for the honour done to me in electing me to the position of President. This, Gentlemen, is the third Presidential address since the amalgamation and incorporation, but we have behind us a record of the work of more than half a century, which we trust will be acknowledged to have been of benefit, both to our own members, and to the profession at large. On looking back on this history I am struck by the many evidences of a progressive and youthful spirit, and although in the case of some members the hair may be white, the heart is still young.

Bearing in mind our past traditions I propose in the few remarks which I have to address to you, to confine myself more especially to those branches of engineering science with which I am personally acquainted, namely, Shipbuilding and Marine Engineering, and also to indicate the lines upon which future development may be expected.

Shipbuilding is one of the oldest of the " Arts and Crafts " and may be said to partake of the nature of both. Man had no sooner attended to his more immediate bodily wants, than his inventive skill was exercised as to means of floating on the waters. The earlier Egyptian drawings show boats constructed of sawn planks, propelled both by sails and oars, and later on, the Greeks and the Romans improved on these early Egyptian models. A further step was reached when the Norsemen constructed their Viking warships, capable of

making voyages of even 2,000 and 3,000 miles. Many, including Dr. Nansen, you will remember, are of opinion that the Norsemen discovered North America long before its re-discovery in the 15th century. The hulls of these boats that have been unearthed have extremely good lines, which are rather narrower and shallower than the proportions adopted at the present day. The size of the ships continually increased, and in the middle ages, owing to the supposed requirements of marine warfare, some most cumbersome and unseaworthy types were developed. There is no doubt that the defeat of the Spanish Armada was largely due to the superior handiness and freedom from top hamper of the English vessels.

It would be tedious to trace out the various steps in the evolution of the modern ocean-going steamer. Gradually the science of shipbuilding was put upon more definite lines, until to-day we have built, or are building, steamers of, in round numbers, 45,000 tons each, whose capacities, displacement and speed can be calculated with almost mathematical accuracy.

In designing a steamer the first step is to study the requirements of the service in which she is intended to be employed, for example for mails and passengers only, or to carry also a limited amount of cargo, or lastly, to be merely a freight carrier, designed to work at the most economical speed. To fulfil any of the above conditions there are numerous intermediate stages, and the object of the designer is so to balance the various requirements as to provide the most suitable compromise for the particular trade. Leaving out of consideration the question of ships of war, undoubtedly the most specialised of all types, and the high-class ocean-going greyhounds, the writer's experience has been mostly in connection with the better class of cargo-carrying steamers, with limited passenger accommodation. The growing tendency among these steamers has been for them to have higher speeds, and the steadily increasing competition between the different lines forces the shipowners to build larger vessels to meet the reduction in freights. The requirements of the merchant are legion. A vessel may be designed to have a small consumption of fuel per ton-mile, but such a vessel may be quite unsuitable for certain purposes. For example the trade may be confined chiefly to perishable cargoes, in which case speed is a more important factor than the saving of a small quantity of fuel. Again, the general internal arrangements of a ship which is built for one trade are unsuitable for, and different from, those for another.

In short journeys between small harbours, ships are constructed to leave port and arrive at their destination at the respective times of high water in each place.

Steamers now are generally built in accordance with the rules of one of the Classification Societies (Lloyd's Register

having by far the largest number built to their requirements) and are subject to periodical surveys, to ensure that the ships are maintained in a sound and seaworthy condition. Other Classification Societies, both in this and in foreign countries, have also done good work in advancing the safety of life and property at sea, and a healthy rivalry has sprung up which is of benefit to all.

The total tonnage of the world's shipping, as recorded by Lloyd's Register, is 43,147,154 tons, of which 38,781,572 tons gross is steam, and 4,365,582 tons net is sail. The number of vessels is 30,087, of which 22,473 are steam and 7,614 sail. The writer appends a table showing the growth in the size of vessels for the last fifty years. The ships named being the largest in existence during the various periods. The "Great Eastern" was long before her time, and consequently what was really the *second* largest vessel in each period has been given in the list down to 1900, for it was not till 1901 that a vessel larger than the "Great Eastern" was built.

In a scientific sense, the hull of a ship can be compared to a beam, which in still water is supported in two places, viz., at the water-borne sections, but at sea, in weather that frequently varies, high waves are met with, which deeply immerse the middle of the structure, or on the other hand leave it largely unsupported, and the object of the naval architect is to meet these varying conditions as economically as possible. For many years the main framing of steamers has been vertical, with longitudinal stiffeners fore and aft to connect the structure, but recently various longitudinal systems of framing have been introduced, which more nearly meet the conditions of the problem, and consequently enable the weight to be reduced. From Lloyd's annual report we see that 38 vessels of 175,299 tons have been built on the Isherwood system of longitudinal framing to Lloyd's Classification, while 34 others of 155,000 tons are now in course of construction. There has lately also been an unusually large demand for steamers intended to carry oil in bulk, which may be explained by the enormously increased use of all kinds of oil engines.

It is unnecessary before a meeting of professional men to enlarge on the luxurious appointments and conveniences of the modern ocean liner, but an idea, tried some thirty years ago in this country, has recently been revived by Mr. Frahm, of Blohm and Voss, to counteract the rolling of ships, and consequent ill-effects on passengers, and damage to cargo. Some seven vessels fitted with the Frahm anti-rolling tank are already in service, which with those now building will make a total of 280,000 tons.

The principle of this ingenious device is the time-worn law of the swing of the pendulum under which the period is

constant for any given length of arm. Bodies that can oscillate about an axis of equilibrium swing strongly when repeatedly acted upon by comparatively small impulses if the period of the impulses is synchronous with that of the oscillating body. For instance soldiers in military formation when crossing a suspension bridge or other light structure are ordered to "break step" in case the period of their step should coincide with the period of oscillation of the bridge.

Now every ship, by reason of her lines, her metacentric height, or other features, permanent, or temporary when due to any particular loading, has a definite and natural period of oscillation or roll; and on the principle of setting a thief to catch a thief, the Frahm anti-rolling tank has been introduced. It utilises a secondary and artificial resonance in order to minimise the influence of the primary resonance between the wave and the ship. The secondary resonance is introduced by a U-shaped tank, in which the water columns can oscillate the same number of times per minute as the ship rolls per minute. As the phases of the impulses of the waves and ship, and ship and tank, lag by 90 deg. there results a total difference of (90 deg. plus 90 deg., equal to) 180 deg., between the waves and tank; thus the water will act in exactly the contrary direction, and greatly minimises the effect of the waves. With such a device on board to scare away the *bête noir* of ocean travellers—sea sickness—a ship-owner should in the future be sure of a full passenger list.

Largely owing to the experiments of Froude at Devonport, and of various builders on the Clyde, the correct form of vessel for a certain speed can be ascertained with great accuracy, the power required being deduced from the performance of the model by certain well known laws. The most recently constructed tank in this country is that at the National Physical Laboratory, the building of which was due to the public spirit of Mr. A. F. Yarrow, M.Inst.C.E., Hon. F.S.E., who gave £20,000 for the purpose. The dimensions of this tank and others at Berlin, Dresden, Paris, Denny's, Japan, and Washington are given on p. 45 of the "Collected Researches" of the N.P.L., Vol. VI., 1910. The Yarrow tank is 500ft. long, 13ft. deep and 30ft. wide, and is thus the second longest, and the first as regards cross-sectional area, on the list.

The enormous increase in the size of steamers has compelled the various port authorities to make still larger docks, with deeper and wider entrances and approaches. One need only mention the names of certain ports in our own country, viz., London, Dover, Southampton, Bristol, Fishguard, Liverpool, Barrow, the Clyde, Rosyth, the Tyne, Grimsby, Immingham, etc., to bring to mind what is being done. The upkeep of these channels and harbours in most cases requires continuous dredging, and where protection against the sea has been pro-

vided by walls and piers, Nature has often resented interference with her old boundaries. In addition, large dry docks, and floating docks are required for the upkeep of the hulls of these vessels.

In addressing a meeting of engineers, one's thoughts naturally turn to the engineering problems involved in the propulsion of modern vessels. As far back as the writer can remember the favourite engine was the old-fashioned side-lever engine, working at 10 to 15 revolutions per minute, with a steam pressure of about 7 pounds per square inch above the atmosphere, driving paddle wheels with fixed floats. The first of the Cunarders was built in 1839. It was about 200 feet long and had a speed of about 8 knots. The last of this company's paddle steamers was the "Scotia," afterwards converted to a screw steamer, and employed in cable laying.

The introduction of the screw propeller, and the consequent demand for a higher number of revolutions, led to a steady increase in the boiler pressure, and established the superiority of the direct-acting inverted type of engine, which holds its own up to the present day. In the meantime, the manufacture of steel has passed from the rule-of-thumb stage, and improved material, together with superior workshop appliances, have made possible the design of boilers for pressures even greater than can be used by the engines, and so the original high-pressure engine has been compounded, tripled, and even quadrupled. Among the earliest of the inverted compound engines were those of the "Murillo" and "Velasquez," built in 1861 by John Elder of Glasgow. These steamers were fitted with Percy Williamson's water-tube boiler. The writer was, for a considerable time, engineer of the "Velasquez," soon after she came out. The water-tube boilers, owing to being surrounded by large masses of brickwork, were unfortunately failures, and had to be removed at the end of the first voyage, and were replaced by the Scotch type of double-ended boiler.

During the long period in which the inverted cylinder engine has been in the field, many modifications in the various parts have been tried, but on the principle of the survival of the fittest, a standard type with unimportant variations has been evolved. The surface condenser was introduced about the middle of the last century, and this important addition allowed the steam pressures to be steadily increased, till to-day, pressures of 200 lb. per sq. in. are common. During recent years, the design of condensers has again been much to the fore; and to meet the requirements of steam turbine practice, the condenser is fitted with an addition known as the vacuum augmentor.

The steam turbine at present holds the field for high-speed

vessels, but has so far been practically confined to fast passenger vessels, and to warships. It depends essentially for its efficiency on a high number of revolutions, and high vacuum. In the case of the "Vespasian" running at moderate speed, the turbine has been geared down to permit of a suitable propeller being fitted. It is now possible to get gearing with an efficiency of 98%, so that while the frictional loss is practically nil, the propeller efficiency is largely increased.

Among several of the large steamers belonging to different lines, a combination of a vertical inverted triple or quadruple expansion engine with a low-pressure turbine has given very satisfactory results. The two systems are each at their best, the engine taking steam at a high pressure, while the turbine makes use of the low pressure and high vacuum.

The steam engine, being a heat engine, depends for its maximum possible efficiency on the range of temperature available, and the obvious method is to increase the initial temperature of the working fluid. Practical considerations limit the boiler pressure, so in recent years renewed attention has been given to superheating the steam. Particularly has this been the case on the Continent, where the Schmidt system has been largely in use for locomotive and marine purposes.

In the beginning of 1910 the writer recommended his firm to adopt this system in one of their steamers, the "Luque," and the consequent economy has been rather surprising. The consumption of coal, as compared with her own previous performances, has been reduced by about 20% over a period of twelve months. During this time she has steamed 31,090 miles on a coal consumption of 2,065 tons, while her sister ship using saturated steam made a distance of 29,697 miles on a consumption of 2,937 tons. In this case the writer was fortunate in having a man to start this new departure who, as Chief Engineer, took a very warm personal interest in its success. It may be of interest to give a few particulars taken on a voyage. The boiler pressure was 175 lb. per square inch, the temperature of the steam averaging 590 deg. F., the temperature of the funnel gases was 480 deg. F. at about one-third the height of the funnel above its base, the temperature of the feed water was 150 deg. F., while the indicated horse-power was 680; these figures being the averages during the voyage. The advantage to the shipowner is increased beyond the monetary value of the coal saved, owing to the extra cargo that can be carried in its place. Encouraged by the foregoing excellent performances, the owners have fitted four more of their steamers with superheaters, and although the time is rather early to speak definitely there is every reason to expect similarly gratifying results.

The internal combustion engine has in recent times been

largely developed and, as instanced in the case of the aeroplane motor, large powers are obtained from an engine of very small weight. In the oil engine type, using light or heavy oils, the fuel is fed direct to the engine, while in the gas engine type, some form of producer is necessary. The saving of weight in the former case is a great consideration for marine purposes, while on the other hand recent developments in the latter type have rendered possible the utilisation of the more common fuel, namely bituminous coal.

The absolute requirements of a marine engine are, that the engine shall be completely under control at any time, and under any conditions ; that is to say, that it can be instantly started, stopped or reversed, and that the speed may be varied to any required extent between full speed ahead and full speed astern. While these conditions have no doubt been sufficiently met for the very small engines, as found in canal boats, fishing boats and the like, it cannot yet be said that a satisfactory solution has been found in the case of the larger types. The success of the oil engine for fishing boats is assured, for an ordinary first-class sailing boat can be supplied and fitted with an oil engine for little more than half the cost of a steam drifter. The speed obtained is very little less, while there is great economy in fuel consumption, as the oil engine only uses fuel when driving, while the steam drifter must lie under banked fires to be ready for action when required. A very strong company has been formed to apply this principle to the propulsion of barges on canals. The consumption of oil, ranging from petrol to the residuary oils, for power purposes must be enormous, and although new fields are being opened up, it is as yet uncertain whether there is sufficient available to supply the motive power for our mercantile marine, and for the many other uses developed in modern practice. Oil fuel is also largely used in our own and other Navies, in the furnaces of steam-driven craft, but so far has not been extensively used in the mercantile marine, possibly owing to the difficulties of supply.

The advantages claimed by the advocates of the oil engine for marine work are :—

1. Less space occupied.
2. No "stand-by" losses.
3. Engine-room staff largely reduced.
4. Less weight of fuel carried and less weight of machinery, consequently more cargo capacity.
5. Elimination of a large number of auxiliaries required for the steam engine.

Among other systems might be mentioned the electric transmission of power from a generating station amidships to

a motor aft, driving the propeller. The objection for moderate speeds has been that the weight of the motor would be considerable owing to the low number of revolutions required when direct coupled, but this might be overcome by gearing down.

Valuable research work in progress also points to a much better understanding of the correct dimensions and form of the high-speed propeller. The prime movers in this case can of course be steam or internal combustion engines, and as the power required can be divided in any required number of units, it can be arranged that only the sets necessary for any speed are in use and working at their most efficient load. This would appear to be a valuable quality in war vessels when cruising.

It is impossible to close these remarks without reference to the Diesel oil engine, now so much in evidence as a serious rival of existing methods of propulsion. The higher the compression in the internal combustion engine, the greater is the efficiency, but with the ordinary Otto cycle the danger of pre-ignition limits the range of compression. In the Diesel engine, the air alone is compressed and the oil fuel is sprayed directly into the cylinder at the commencement of the working stroke, and the supply continued for some time during the stroke. The compression of the air has of course raised its temperature and this is carried to such a point that the temperature is sufficient to ignite the sprayed oil, which with the air forms an explosive mixture. This compression is to about 700 lb. per square inch. An air-compressor worked off the engine itself is used for starting purposes, and the speed of the engine is governed by reducing or increasing the supply of fuel. The Diesel is probably the most economical engine at present known, the consumption of oil being about $\frac{1}{2}$ lb. per brake horse-power hour, a further advantage being its capacity to make use of the cheap residuary oils. This engine is, in common with other engines, subject to the difficulties of reversing, which is accomplished in the smaller types by mechanical gearing, although the writer understands that recent improvements are likely to overcome this difficulty. The "Vulcano," a vessel of over 1,000 tons register, fitted with Diesel engines of the four-stroke cycle, has already made several voyages with good results as to economy and reliability. There are at the present time building, or projected, about a dozen vessels to be fitted with oil engines, mostly of the Diesel type. These are vessels of considerable size, ranging up to as much as 8,000 tons gross register (it is also reported that a 14,000-ton vessel is being built on the Continent), and if, as there is no reason to doubt, the results prove satisfactory, there will be a considerable reduction in the cost of sea transport.

Table showing names and tonnage of the largest steamers in existence in each year since 1858:—

Years.	Name.	Tons Gross.
1858	Great Eastern	18,915
1862 to 1873 ..	Scotia	3,871
1874 to 1880 ..	Germanic	5,008
	Brittanic	5,004
1881 to 1888 ..	City of Rome	8,144
1889 to 1891 ..	City of New York	10,499
	City of Paris	10,499
1892	Campania	12,950
1893 to 1896 ..	Lucania	12,952
1897 to 1898 ..	Kaiser Wilhelm der Grosse	14,349
1899 to 1900 ..	Oceanic	17,274
1901	Celtic	20,904
1902	Cedric	21,035
1903 to 1904 ..	Baltic	23,876
1905	Kaiserin Auguste Victoria	24,581
1906 to 1910 ..	Mauretania	31,938
1911	Olympic	45,324

Mr. J. W. Wilson moved a vote of thanks to the President for the very interesting address which he had just delivered. The subject with which he had mainly dealt was second to none in its combination of very important questions of theory and equally important facts of practice. The Society of Engineers was not restricted to any special branch of engineering ; all were equally acceptable to it ; but it would be interesting for the members during the coming year to feel that they had at their head one who was following the marine engineering branch of the profession ; he did not remember that this had ever before been the case. The meeting was not entitled to discuss the points which the President had brought forward ; but they might hope that during his year of office some of the papers read at their meetings might point in the direction taken by the address ; this would be a novelty for the Society, and he was sure that the members would welcome it. The President had touched upon the early history of the subject, and he had brought the matter up to date in many important points ; and he had not hesitated to a certain extent to prophesy as to the future. The questions which he had brought forward were very worthy of consideration. All could see, for example, that there was something very important in the development of the internal combustion engine for marine work ; and the next few years would enable engineers to set at rest many such questions which now were troubling them. He was sure that they would all join very heartily in according a vote of thanks to Mr. Kennedy. A President during his year of office

worked very hard. Mr. Bloyd, their retiring President, had certainly done so ; and few people could realise the amount of work which was really involved. Therefore the members of the Society owed a debt of gratitude to their Presidents ; and the best way in which they could show it was by supporting the President and the Council by coming to the meetings. Of course, if they felt inclined they would take part in the discussions ; but at any rate they would show by their presence that they appreciated what was being done ; and the same remark would apply to the visits to works which were arranged during the summer. He was sure that the Society was at the beginning of a very prosperous year ; and he asked the members to pass a very cordial vote of thanks to the President for his address, and to give him an assurance that they would all do their part to make it so successful that he would be able to say at the close of it what Mr. Bloyd had already said, namely, that it was one of the happiest years he had spent.

Mr. H. C. H. Shenton said that it was his privilege to second the vote of thanks to the President for his address. It was a great pleasure to all of them to see Mr. Kennedy in the Presidential chair, both on personal grounds and because of the important branch of the engineering profession which he represented. It was also refreshing to have an address upon a subject which had not been dealt with before the Society for a great many years. He was sure that they all wished the President a most successful year of office. He felt sure that everyone would support the President in the way in which Mr. Wilson had so ably outlined.

The vote of thanks was carried by acclamation.

The **President** thanked the meeting very warmly for the very kind way in which they had received the vote of thanks. He was quite sure that during his year of office he would be well supported by the members of the Society.

SOCIETY'S PREMIUM ACCOUNT.

To Premiums	...	...	...	£ s. d.	£ s. d.
" Gold Medal	...	...	...	5 17 0	22 12 4
" Balance carried to next Account	...	...	...	5 0 0	10 10 0
	...	...	...	22 5 4	
				<u>£33 2 4</u>	<u>£33 2 4</u>

By Balance, 1st January, 1911 ...
 " President's Donation ...

NURSEY MEMORIAL FUND.

To Balance at 1st January, 1911	...	...	...	£ s. d.	£ s. d.
" Printing	...	...	...	4 14 10	1 14 2
	...	...	...	0 4 6	3 5 2
				<u>£4 19 4</u>	<u>£4 19 4</u>

By Dividends ...
 " Balance carried to next Account

BESSEMER TRUST FUND.

To Premiums	...	...	...	£ s. d.	£ s. d.
" Balance carried to next Account	...	...	...	5 6 0	5 4 6
	...	...	...	5 3 0	5 4 6
				<u>£10 9 0</u>	<u>£10 9 0</u>

By Balance, 1st January, 1911 ...
 " Dividends ...

J. BERNAYS' LEGACY.

To balance carried to next Account	...	...	...	£ s. d.	£ s. d.
	...	...	...	1 14 10	0 17 5
				<u>£1 14 10</u>	<u>£1 14 10</u>

By Balance, 1st January, 1911 ...
 " Dividends ...

We have examined the above Balance Sheet and accompanying accounts and have obtained all the information and explanations we have required. In our opinion the Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state of the Society's affairs, according to the best of our information and the explanations given to us and as shown by the books of the Society.

23, Queen Victoria Street, E.C.,
 24th February, 1912.

(Signed) W. B. KEEN & CO.,
Chartered Accountants.

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31st DECEMBER, 1911.

	£	s.	d.	£	s.	d.	£	s.	d.
To Printing Transactions	197	13	6						
Less Sales and Advertisements	38	3	2						
				159	10	4			
„ Law Lectures: Printing, Lecturer's Fee and Hire of Rooms	34	15	0						
Less Sale of Tickets and Volumes	23	5	11						
				11	9	1			
„ Administration Expenses—									
Salary of Secretary	300	0	0						
Rent of Offices	85	0	0						
Fuel, Lighting, Office Cleaning, and Repairs	20	7	2						
Postage, Telegrams, Carriage and General Expenses	82	18	3						
Stationery and General Printing	88	5	9						
Audit Fee	10	10	0						
				587	1	2			
„ Meeting Expenses—									
Hire of Rooms	19	15	0						
Reporting Meetings	16	16	0						
Refreshments for members at Or- dinary Meetings	7	12	10						
				44	3	10			
„ Employment Bureau—									
County Council Fee	1	1	0						
Less Deposits forfeited	0	10	0						
				0	11	0			
„ Dinners (January and May) Balance...	63	6	4						
„ Vacation Visits Balance	1	10	9						
„ Law Charges	6	3	6						
„ Depreciation on Office Furniture	4	7	11						
				£878	3	11			
							£878	3	11

4th March, 1912.

JOHN KENNEDY, PRESIDENT,
IN THE CHAIR.

THE TROLLEY VEHICLE SYSTEM OF RAILLESS TRACTION.

By HENRY C. ADAMS, Assoc.M.Inst.C.E., M.I.Mech.E.,
A.M.I.E.E. (Member of Council.)

THE trolley vehicle system of railless traction is a comparatively recent development so far as this country is concerned, and the literature on the subject is by no means voluminous, so that some brief description of it in its various forms should prove interesting to the members of this society and be provocative of a good discussion.

Briefly the system may be described as consisting of mechanically propelled vehicles adapted for use upon roads and moved by electrical power transmitted thereto from some external source. The power is obtained from bare overhead conductors erected and fixed in a manner somewhat similar to that now so familiar in connection with the side-swivelling trolley electric tramway systems, except that as there are no steel rails to take the return current, a second overhead wire is necessary for the purpose. The vehicles are fitted with trolley poles, or other connections, for completing the circuit between the overhead wires through the motors on the car. The system of double overhead wires, one positive and the other negative, was introduced in America some 25 years ago, and was known as Short's system. It was adapted for use by ordinary electric trams, the current being collected by a four-wheeled trolley running on the wires and conveyed to and from the cars by a flexible cable.

The four principal methods of applying the trolley omnibus system abroad are the "Max Schiemann," "Mercedes-Stoll," "Lloyd-Köhler" and the "Filovia," which will be described later. There are in addition several British companies at work who have devised many improvements on the original methods and have adapted the system to British ideas. Installations have been working abroad for some years in Vienna, Dresden, Bremen, Drammen, Spezia, California and about 30 other places; there being 50 miles in Italy alone. It was first definitely suggested in this country in November 1902, when the Stroud District and Cheltenham Tramways Bill was deposited in Parliament. In 1903 a comprehensive scheme was designed for linking up Tunbridge Wells with Tonbridge and other surrounding places.

The Dundee Corporation obtained powers for the installation of this system in their Order of 1907 and the approval of the Board of Trade to the plans has been obtained. In 1908 the Tramways Engineer of Manchester recommended its adoption in that city, but at the statutory meeting of ratepayers convened in pursuance of the Borough Funds Act, the clauses relating to it were struck out of the proposed Bill, mainly owing to the opposition of the cab and omnibus proprietors and other interested parties. The next towns to take the matter up were Leeds, Bradford and Sheffield. In September, 1909, trial trips with an experimental car were run at Hendon. Bills were deposited in Parliament in November, 1909, on behalf of the Leeds and Bradford Corporations respectively, and they eventually received the Royal Assent in July, 1910.

In November, 1910, there were fifteen bills deposited in Parliament as follows :—

- Aberdare Urban District Council.
- Brighton, Hove and District Railless Traction.
- Brighton District Tramways.
- Chiswick Urban District Council.
- Croydon and Southern District Railless Electric Traction.
- Halifax Corporation.
- Macclesfield and District Railless Electric Traction.
- Malvern Electric Traction.
- Matlock District Railless Traction.
- Newcastle-upon-Tyne Corporation.
- Northampton Corporation.
- Oldham and Saddleworth District Railless Electric Traction.
- Rotherham Corporation.
- Rotherham, Maltby and District Railless Electric Traction.
- Western Valleys (Monmouthshire) Railless Electric Traction.

Powers were obtained at Aberdare, Brighton, Chiswick, Halifax, Northampton and Rotherham.

Eleven Bills were deposited in November, 1911, for the current session of Parliament seeking powers to instal this system of traction as follows :—

- Brighton Corporation (Capital £100,000).
- Brighton, Hove and District Railless Traction (Promoted by Brighton, Hove and Preston United Omnibus Co., Ltd.)
- Hove Corporation Railless Traction (Capital £100,000).
- Keighley Corporation (Capital £47,970).
- Lanark County Council.
- North Ormesby, South Bank, Normanby and Grangetown Railless Traction (A new company to be formed with a capital of £40,000).
- Ramsbottom Urban District Railless Traction (Capital £16,000).

Sheffield Corporation (Capital £40,681).

Southall, Hounslow and Twickenham Railless Traction
(A new company to be formed with a capital of £18,000).

Stockport Corporation (Capital £11,000).

West Ham Corporation (Capital £7,100).

The Corporation of Birmingham gave notice in due form of its intention to apply for power to run trackless trams but did not include provisions for it in the Bill which was subsequently deposited.

An interesting episode occurred at Brighton. It will be noticed that in 1911 session there were two Brighton Bills, the Brighton, Hove and Preston Omnibus Co. promoting one in opposition to the proposed tramway scheme. As a result of the opposition of the local authorities to the other portions of the Bills the only powers granted were obtained by the Omnibus Co. for a line between Black Rock, Brighton and Rottingdean, the construction of which is now starting and which will, when completed, supersede the present service of motor omnibuses. In the present session the Omnibus Co. have reintroduced their Bill and the Brighton and Hove Corporations have deposited similar Bills ; all three schemes being identical. In the early part of this year statements appeared in the public press purporting to be authoritative on behalf of each of the several parties and intimating that they did not desire to instal the railless system but had been forced to promote their Bill solely on account of the action of the others ; the manager of the Omnibus Co. being reported as saying that not only were his company prepared to drop their present Bill if the other parties did likewise, but would give an undertaking not to promote a Bill at any future time except in self-defence.

In all the Bills deposited provisions are included to enable the Board of Trade to make Provisional Orders authorising the use of railless trolley vehicles on other routes additional to those specified in the current applications, and to prescribe the procedure to be followed in applying for such Provisional Orders, so that if the powers are granted future Parliamentary Bills will be unnecessary in these places when it is desired to make extensions. It is understood that the Board of Trade are considering the question of simplifying and cheapening the procedure by means of Provisional Orders similar to those for tramways or light railways instead of having to proceed by Bill as at present.

The subject is being discussed with a view to its installation in many towns all over the country, while to come nearer home the London County Council and the Metropolitan Electric Tramways Company have decided to investigate its possibilities. The Leeds and Bradford schemes were completed and opened to traffic on the 20th June, 1911, while the lines at Dundee and Rotherham will probably be at work when this paper is read.

Although the Bradford system was installed as recently as last June proposals for extensions are already on foot, owing to the report of the General Manager detailing the success of the short length at present in operation. Negotiations are also in progress for the installation of the system at the end of other of the tramway routes on the outskirts of Leeds.

Looking abroad it is to be noted that the Bloemfontein Town Council have decided to make arrangements for the installation of this system, and the Krugersdorp Council are considering its adoption on a route 9 miles in length, while the "Trackless Trolley" Company (Mercedes-Stoll System) have orders both for Australia and South Africa.

The Ramsbottom Urban District Council propose to use railless cars on routes the majority of which were authorised previously for tramways, because when their Tramway Bill was passed the Lancashire and Yorkshire Railway obtained the insertion of a clause requiring the construction of either a bridge over, or a tunnel under, their line, for the trams in one of the roads in lieu of a crossing on the level as originally proposed. The only other means of crossing the railway was by a bridge which was not suitable for tramway traffic, and as the estimated cost of meeting the railway company's provision was too great to be entertained, the tramway scheme was hung up and the residents debarred from the extra travelling facilities they desired, but the advent of trolley-omnibuses, which would be able to run over the existing bridge, offered a solution to the difficulty which they will be able to take advantage of if their present Bill is passed.

This brief historical resumé of the progress of the system up to date is sufficient to show that it has long passed the experimental stage and that those engineers who have kept in touch with it in its various phases have now sufficient data to enable them to give reliable advice and to carry into effect schemes which would prove financially satisfactory and generally advantageous to the community.

There are many localities where additional means of transport are urgently required but the probable traffic is not sufficient to warrant the outlay necessary to construct an electric tramway. Now that people have become accustomed to the appearance of the overhead work most of the objection to tramways centres around the track, and its omission in the trolley omnibus system considerably facilitates negotiations for the adoption of the latter. Objection is raised on the part of the drivers of narrow-tired horse vehicles to the presence of the grooved tram rails in the road and to the varying material forming the surface of the road in places where the carriageway margins are constructed in macadam and the tramway track is laid with wood or granite blocks. The junction between the two materials along the

whole route, on both sides of the tramway, requires constant attention and rarely remains in good condition for long, while in narrow roads the width of the macadam between the channel stones and the tramway margin is not sufficient to permit of steam rolling. If there is a frequent service of trams, horsed vehicles are perforce concentrated to a great extent on the narrow macadam portions, which thus have to carry a greatly increased traffic, as measured per foot in width of road utilised. The noise of the trams is also an objection to their use under certain circumstances. A trackless system can be installed without there being any necessity for expenditure in road widenings, so frequently required in tramway schemes, and the flexibility of the system will allow tradesmen's carts to stand outside the shops without having to be moved out of the way, as is now required in narrow streets, every time a tramcar passes. In fact this method of traction can be, and is, employed in roads which are too narrow even for a single line of tramway with passing-place loops.

Until recently the only alternative to a tramway was the self-propelled motor omnibus, and although at the present time in London the most recent additions to the service leave little to be desired in reliability, comfort, speed and economy, there is no doubt that the same result has not been obtained with the smaller fleets tried from time to time in provincial towns. It does not follow, however, that success is impossible, and better results may be obtained with a general adoption of the latest improved type of omnibus. The engine and fuel which all self-propelled vehicles have to carry add considerably to their weight, and consequently to the dead load to be carried, which involves an increased consumption of power. The extra load also increases the wear of the tyres, an important item of expense. It is cheaper to generate power in bulk for a whole fleet of vehicles than to do so separately for each individual vehicle, but in the former case it is necessary to add the cost of transmitting the power along the routes. There is the other aspect of the case, namely that if the generating plant at the central station breaks down the whole system is stopped, whereas if the motor of a self-contained vehicle breaks down, only that vehicle is put out of service; the former, however, is a much more remote contingency than the latter. The motor omnibus and the trolley omnibus can be steered with equal facility in crowded narrow streets.

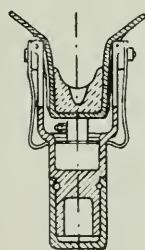
In addition to those places where there are now no regular means of transport, the railless system of traction is specially fitted to form extensions beyond the termini of existing tramway systems. In these cases the trolley omnibuses would not only feed the tramways but would create a traffic of their own, so that ultimately, when the time was ripe, tramway tracks

could be laid down if desired, and provided the contingency has been anticipated in the design, the overhead work could be re-arranged at very little cost to meet the requirements.

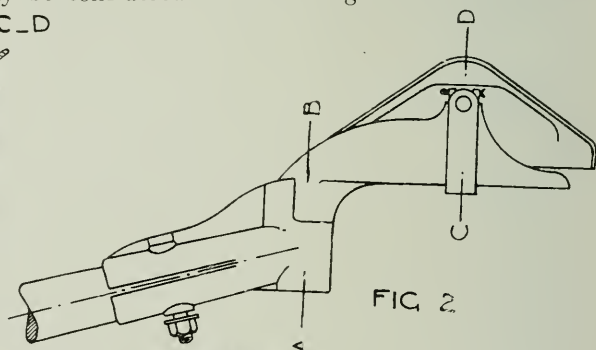
It is important where the railless routes are an extension of the tramway system that the trolley on the omnibus should be of such a pattern that, provision being made for the return current, it can be used to obtain power from the overhead tramway wires; because in the majority of instances it will be found that such routes are at some distance away from the tramway depot to which the omnibus will have to return each night.

Doubtless some extra revenue might be obtained by supplying electric power to private consumers *en route*, by conveying goods and parcels through the streets, and also by permitting the use of the overhead wires and current by privately owned vehicles fitted with the necessary equipment; but in this latter case stringent conditions would have to be framed to prevent any delay to, or disorganisation of, the public service. In a general way these possibilities might be somewhat remote and therefore could hardly be considered as influencing the installation of a

SECTION C-D



SECTION
A-B
FIG. 1



FIGS. 1 & 2.—DETAILS OF SINGLE "SCHIEMANN" TROLLEY HEAD.

FIG. 3.—SKETCH OF "SCHIEMANN" DOUBLE CONTACT TROLLEY HEAD.

system, or the routes to be taken, but that is no reason why such sources of revenue should not be developed to the fullest extent.

There is no doubt that a judicious adoption of this method of traction will result in very considerable advantage to the dwellers in the smaller towns, also to those residing in the suburbs of the larger towns, and in the less remote rural districts in the vicinity of such towns.

The "Max Schiemann" system is the oldest, being brought out in 1900 and now in use at some 14 places abroad, including Drammen, Monheim, Wurzen, Mulhausen and California.

The positive and negative overhead wires are placed parallel, about 6in. apart and 17ft. above the surface of the ground. The current is conveyed between the omnibuses and the wires in alternative ways. In one method two trolley booms are fixed on top of the cars, one behind the other; the collectors being under-running and making a sliding contact, and formed as shown in detail in Figs. 1 and 2. In the other method one trolley boom only is employed, fitted with a special lubricated double sliding contact collector as shown in Fig. 3.

The cars are driven by a single motor from 15 to 25 h.p. running at 1,200 revolutions per minute and placed under the

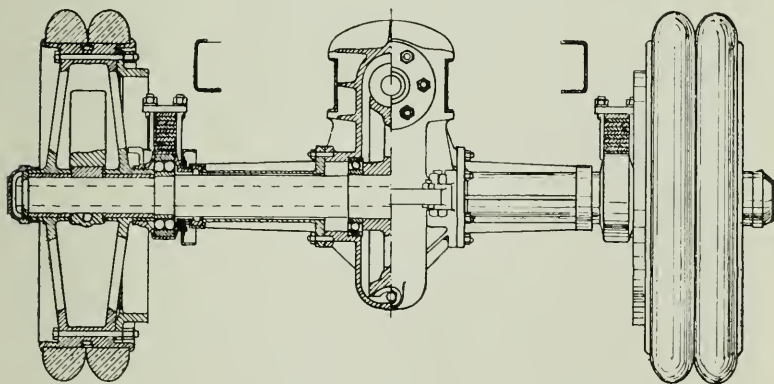


FIG. 4 DRIVING WHEELS OF "SCHIEMANN" VEHICLE

driver's seat, whence power is transmitted to the rear axle through spur gearing, by a shaft longitudinal with the vehicle. The axle revolves and drives the wheels through interlocking movable fingers; the wheels are fitted with ball bearings. The controller is actuated by a hand lever and gives three running speeds, the resistances being carried in a frame under the body of the vehicle. The tyres are of solid rubber, single on the front wheels and twin on the rear. Fig. 4 shows a part elevation and part section of the rear wheels and driving gear.

The cars on the California route maintain a speed, under favourable conditions, of 25 miles per hour, while up the maximum gradient of 1 in $8\frac{1}{3}$ a speed of 8 miles per hour is maintained. At Munich the cars are allowed to travel as fast as 20 to 30 miles per hour and this speed is obtained by simply raising the line voltage from 500 to between 600 and 700 volts. The traction co-efficient of one of the early 24-passenger cars was found to be 55 to 66 lb. per ton on a level road.

The "Mercedes-Stoll" system is in use on nine routes in Austria, Hungary and Bohemia, four of the routes being in the neighbourhood of Vienna. The first line was opened in July, 1907. It is now being installed also at Fribourg (Switzerland), Paris, New York and Berlin, as well as in Australia and South Africa. The English company exploiting this system is the Trackless Trolley Limited.

In this system the positive and negative overhead wires are placed side by side at a distance of 12in. apart and about 21ft. above the surface of the ground. The current collector con-

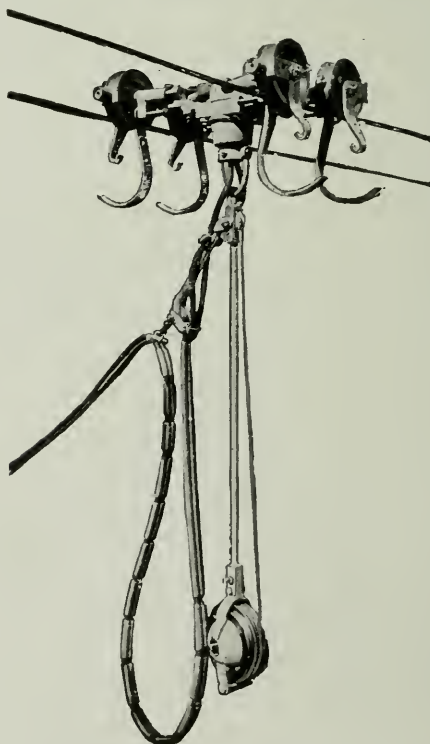


FIG. 5—"MERCEDES-STOLL" CURRENT COLLECTOR.

sists of a small four-wheeled trolley as shown in Fig. 5. The wheels are fitted with ball bearings and are grooved, one pair running on the positive wire and the other pair on the negative. A weighted pendulum is suspended from the frame which not only keeps the wheels pressed down on the wires but throws the centre of gravity of the collector so low that the pull of the car through the cable, acting as it does on the short leverage of the link under the frame, does not displace the collector. Even if by some means the collector left the wires it would be prevented from falling into the road by the safety hooks fitted to each wheel. The collector only weighs 25 lb. and is easily

placed on the wires by one man, as is clearly shown in Fig. 6, Plate 1. It should be added that the company have designed an ordinary double under-running pole attachment to the car for use in localities where there are objections to the over-running trolley; this, however, adds about 4 cwt. to the dead weight of the vehicle. The cable is a twin one and is looped where it joins the frame so as to allow for extension to absorb any sudden jerk from the car. This extension is effected by means of a spring fitted into the weight of the pendulum and connected to the cable by a flexible wire. About 10 yards of the cable at the car end is coiled on a drum having a spiral spring which automatically winds the cable up or lets it out as required so that the vehicle possesses a very wide range of movement. A ball-and-socket joint is fitted between the cable

and the collecting trolley which enables the car to describe circles underneath the trolley so that when a single set of wires is used the direction of travel can be reversed without it being necessary to interfere with the trolley or the connecting cable. Fig. 7 shows the cable drum, vertical rod holder, sliding rod, steering wheel, controller, and brake pedal.

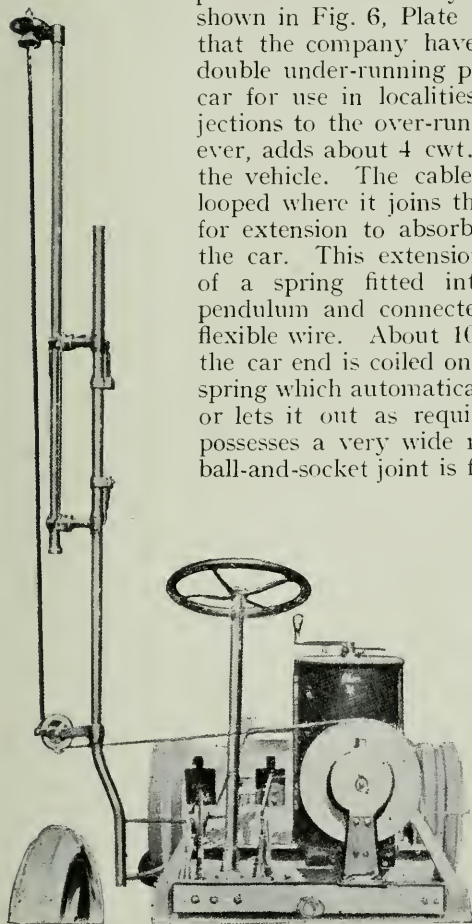


FIG. 7.—CABLE DRUM AND VERTICAL CABLE HOLDER.

In order to permit the cars to pass each other when only one set of overhead wires is employed a connecting link is fitted in each cable so that after the slack is wound in the car can be disengaged from the overhead collector. When desirous of passing, the two vehicles are drawn up opposing each other with the front axles approximately in line, as illustrated on Plate I. ; each driver draws down the sliding rod, separates his cable and hands the loose end of the hanging cable across to his colleague who connects it up with his car. It is said that this exchange can be effected in 8 seconds. After having performed the operation each vehicle can proceed in its original direction. The connecting link on the cable can be seen in Fig. 8 to the left of the trees just above the sliding rod of the right-hand omnibus. This connector is so formed that it would separate automatically if by any means the cable fouled any passing obstruction or the car was driven to too great a distance from the overhead wires. This last illustration also shows a terminal curve which enables the direction of the vehicles to be reversed at the end of a route, in a wide sweep, without backing them. In the centre of the rear wheels of the left-hand omnibus the motors which form the most distinguishing feature of the design of these vehicles can be seen. The standard power of these is 20 h.p. each, they run at 200 r.p.m. and are specially designed to resist the road shocks. A car speed of 14 miles per hour is attained. The field magnets of the motors are fixed on the axle and form the nave of the wheel, the rest of the wheel being mounted on ball bearings there is thus no loss of power in transmission. The cover hermetically closes the motor and protects it from dust, as well as fixing it securely on the axle. The motors fixed on the 18-passenger cars running on the Gmund line in Northern Austria, which was opened in July, 1907, have now run over 100,000 miles without any attention, saving that necessitated by external physical damage, and, according to the report of the Superintendent, are still working in a faultless manner. Cars designed for use with trailers are fitted with two extra motors on the front wheels. There is no transmission gear, and the weight of the motor being direct on to the wheel the springs may be made fairly light and flexible as they only have to support the bare chassis and body, together with the passengers. The controller is of the tramway pattern of the usual drum type ; it is reversible, and for reversing purposes a separate reversing barrel is employed inside the controller itself and operated by a separate key, but so interlocked with the main barrel that it cannot be reversed unless the main barrel is in the open position. The drum of the controller is insulated throughout with mica, and is provided with six speeds forward and three rheostatic braking points. The contacts on the drum are renewable and of hard drawn copper ; the fingers are of the usual type supported from brass carriers which

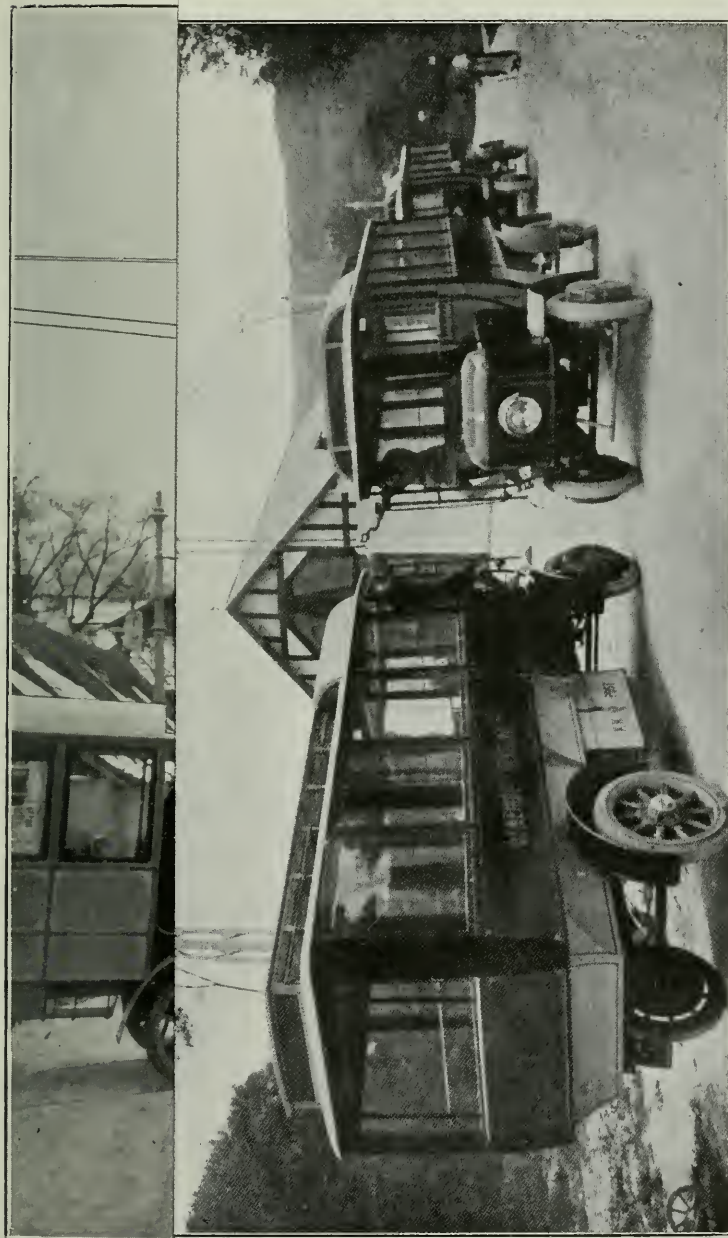


FIG. 6a.—EXCHANGING COLLECTORS IN PASSING.



FIG. 6.—PLACING "MERCEDES-STOLL" COLLECTOR ON WIRES.

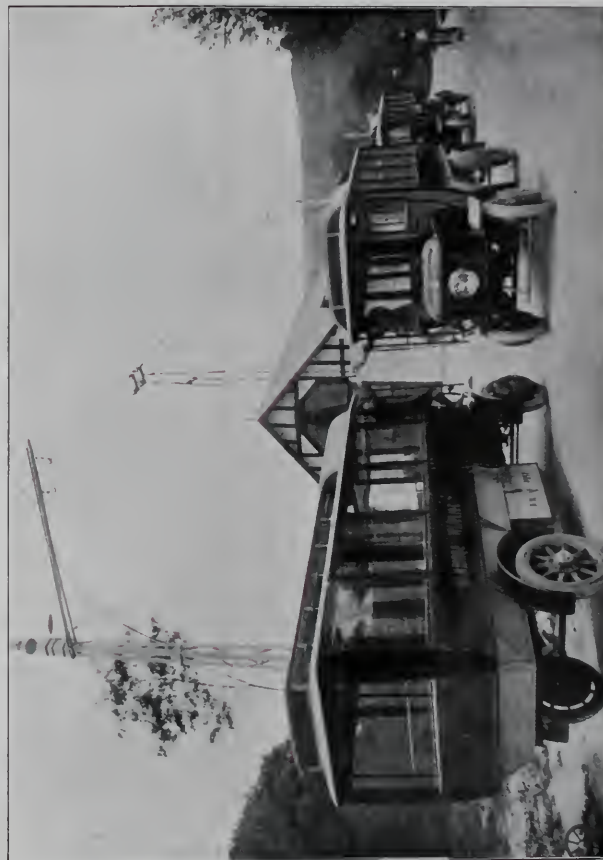


FIG. 6a.—EXCHANGING COLLECTORS IN PASSING.



FIG. 8.—“ MERCEDES-STOLL ” CARS ON TERMINAL CURVE.

are in turn supported by an iron bar and insulated therefrom with mica. A powerful blow-out coil is provided to act for all contacts; there is also an arrangement for cutting out either motor as occasion may require, and this is so arranged that it is impossible for the driver to short-circuit the line with the controller in parallel position after one motor is cut out. The resistances are of the usual standard type and of two-minute rating. The brakes act on the rear driving wheels. The tyres are of solid rubber with single treads on the front wheels and

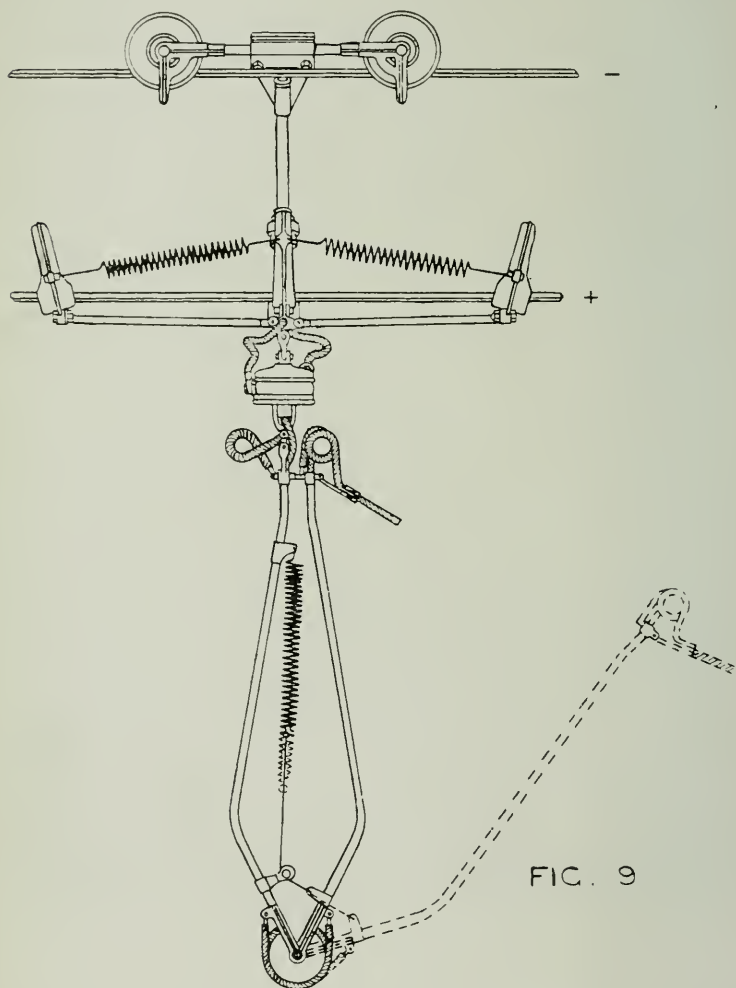


FIG. 9

FIG. 9.—SIDE ELEVATION OF "LLOYD-KÖHLER" CURRENT COLLECTOR.

twin treads on the rear wheels. The weight, loaded, of a car holding 26 passengers is 4 tons 10 cwt. The line voltage varies from 450 to 600 on the different routes in operation.

The "Lloyd-Köhler" system is in operation at Bremen, Germany, upon two routes, one between Arsterdam and Arsten, and the other, which is run in the summer only, from the centre of the town to a public park on the outskirts. Each route is approximately 2 miles long. It has also been installed on a route $8\frac{1}{2}$ miles long at Ludwigsburg, and also at Breslau. Further schemes are now under consideration.

The overhead wires, in this system, are placed one above the other at a distance apart of 11 ins. The upper one is negative and would therefore act as a guard wire to prevent any falling

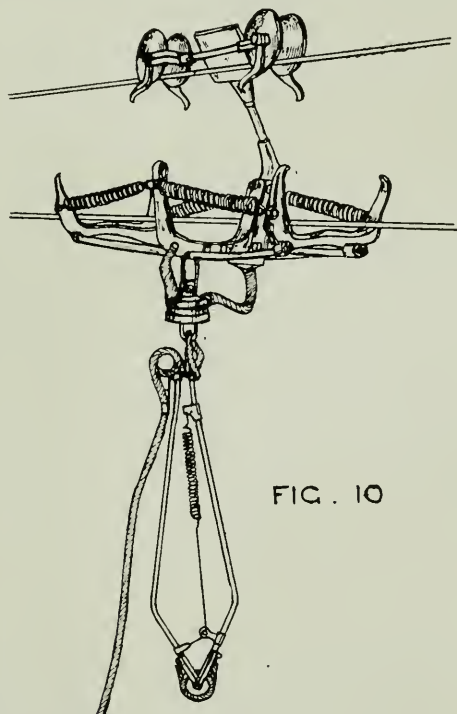


FIG. 10

FIG. 10.—SKETCH OF "LLOYD-KÖHLER" CURRENT COLLECTOR.

telegraph or telephone wires coming in contact with the lower or positive wire. The current collector is shown in Figs. 9 and 10. Its weight is carried by the upper wire, on which the two-wheeled trolley forming the upper part of the collector runs. A short metal horn is formed on both sides of each wheel to

prevent the carriage slipping off the wire. The lower part of the apparatus, which is the actual collector, consists of a stirrup and two aluminium sliding bows permitting the whole thing to swing laterally over a considerable arc, as can be seen from Fig. 11, which shows the extreme positions the trolley wheels and bows may take up. There is no danger of it falling to the ground as the clearance between the stirrup and the lower

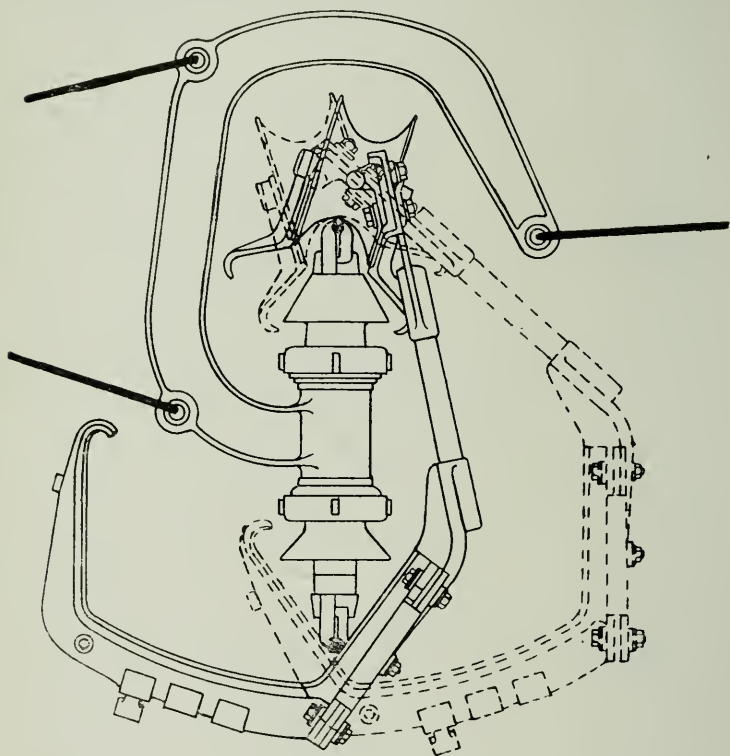


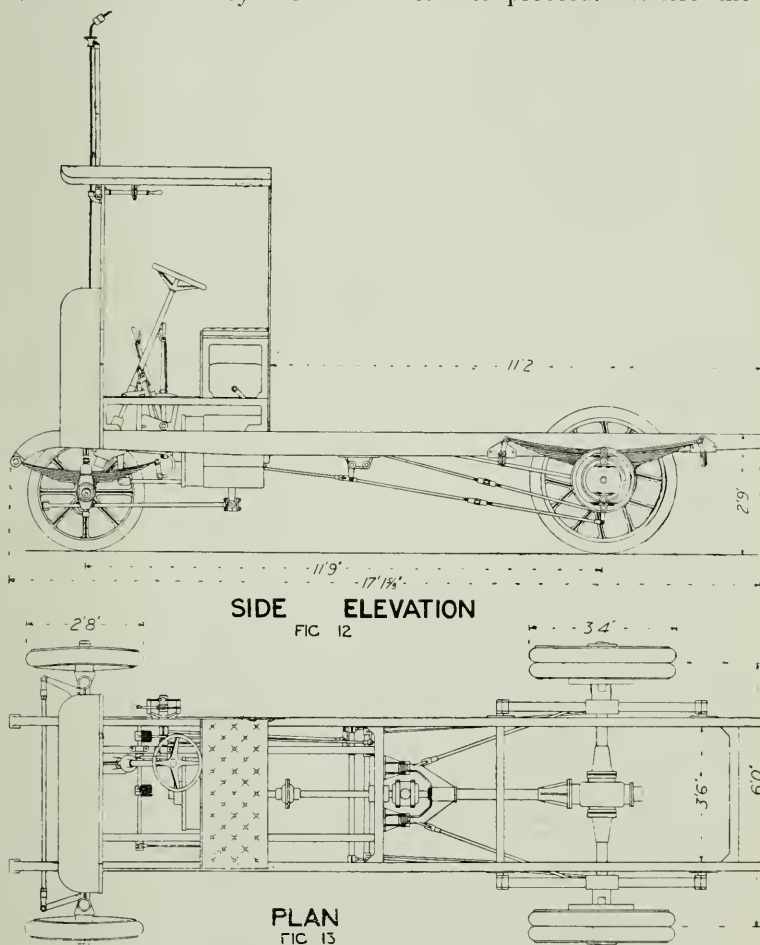
FIG. 11

FIG. 11.—DIAGRAM SHOWING RANGE OF MOVEMENT OF " LLOYD-KÖHLER " COLLECTOR.

wire is so small that the collector cannot rise sufficiently for the wheels to leave the upper wire. The bows are hinged at their connection with the central stirrup and are thus free to move vertically. They are drawn up by means of two springs to each bow, to make contact with the wire. The cable is a twin one and passes through a hinged metal loop arrangement attached to the collector to relieve the latter from any sudden jerk from the car when starting or stopping. The two arms are drawn up

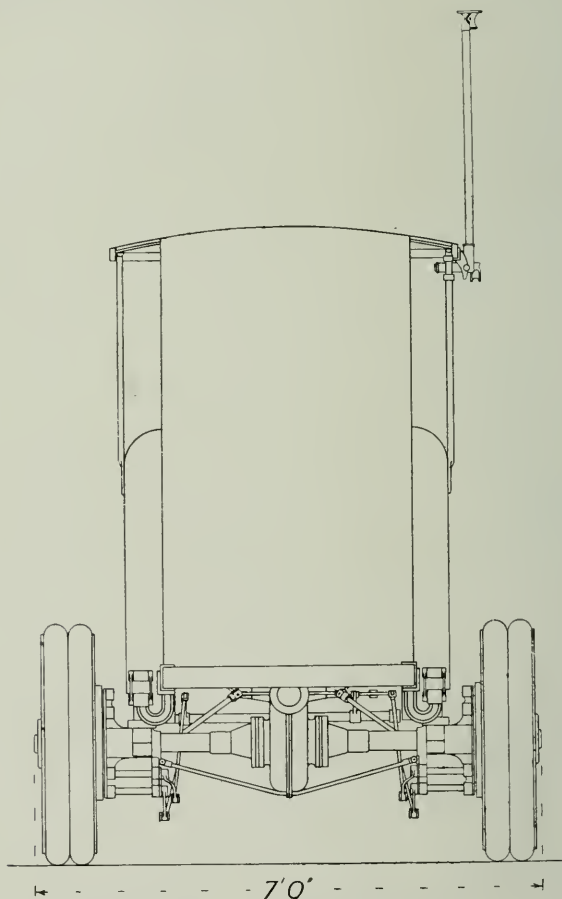
towards each other by a light spring. At the car end the cable is wound on a drum as already explained in the Mercedes-Stoll system, to give a wide range of movement and allow the car to pass freely in and out through other traffic.

The passing of two vehicles travelling in opposite directions is effected by exchanging collectors in the same manner as in the Mercedes-Stoll system, except that the cable post is so arranged that by pulling down a handle placed immediately above the driver's seat the upper part of the post with the collector is brought within easy reach, thus facilitating the exchange, which occupies from 15 to 20 seconds from the time the cars stop to the time at which they are in readiness to proceed. Where the



FIGS. 12 & 13.—DETAILS OF "BRUSH" CHASSIS.

traffic is sufficient to justify two sets of overhead wires the cars can, of course, run past each other in opposite directions without stopping, but if at any time one of the cars broke down an overtaking bus would not be delayed but could pick up the collector previously used by the first car and proceed at once. There is no obstruction to the use of the positive wire by an electric tramcar with ordinary under-running trolley boom, travelling in the same direction ; and in special cases where the route of a tramway crosses the trolley omnibus route the overhead work can be designed without difficulty to admit of through-running in the cross directions.



BACK ELEVATION

FIG. 14

FIG. 14.—BACK ELEVATION OF "BRUSH" CHASSIS.

The details of a chassis specially designed by the Brush Electrical Engineering Company for use with this system and having a carrying capacity of about 3 tons in addition to the body are shown in Figs. 12, 13 and 14. The wheels are of cast steel and run on ball bearings mounted on the axle casing; they are fitted with solid rubber tyres, 4in. single on the front wheels and 4in. twin on the rear. The tyres are guaranteed to run 12,000 miles. Power is transmitted to the rear axle through a propeller shaft running inside a tube, which is anchored to the frame, thus taking the torque from the rear axle. A universal joint is provided at the front end of the shaft to compensate the rise and fall of the rear axle. At the back end of the shaft a hardened steel worm is fitted, running on ball bearings and gearing with a phosphor bronze worm wheel mounted on the differential box. The propeller shaft is connected to the motor shaft by means of an intermediate shaft and couplings.

The motor is of the drum armature 4-pole type, series-wound, and capable of giving, at 500 volts D.C., an output of 25 b.h.p. at the road wheels for one hour continuously, with a temperature rise of not more than 135 deg. F. The bearings of the motor are of ball-bearing type and adapted for grease lubrication. A thrust bearing is provided to take the weight of the armature when the vehicle is on a gradient. The main control—from starting to full speed—is operated by the foot pedal on the left-hand side; the reverse and electric brake are operated by hand lever. These are interlocked in such a way that the current must be cut off by the pedal before the reverse and brake control handle can be used. This allows the driver to have both hands on the steering wheel while controlling the speed of the vehicle.

The controller is of the drum type made up of two parts, one for starting and regulating the speeds and the other for reversing and applying the rheostatic brake in either direction. It is placed under the driver's seat and has running notches for one-third, two-thirds and full speed, in addition to the speed control which the three notches of the starting resistances give. Two mechanical brakes are fitted, one operated by the foot pedal on the right-hand side, and the other by a hand lever. They both act on separate brake drums attached to the hubs of the rear wheels. The weight, unloaded, of a vehicle seating 24 passengers, complete, is 3 tons 12 cwt. Fig. 15 shows the latest type of vehicle and also the overhead construction at a turnout.

The vehicles at Bremen are of the single-deck type and have a seating capacity of 16 with ample standing capacity, they are each fitted with one motor of 18 b.h.p. normal, and 35 b.h.p. maximum, running at 650 revs. per minute on 550 volts. The power consumption is 600 watt-hours per car mile. The maxi-

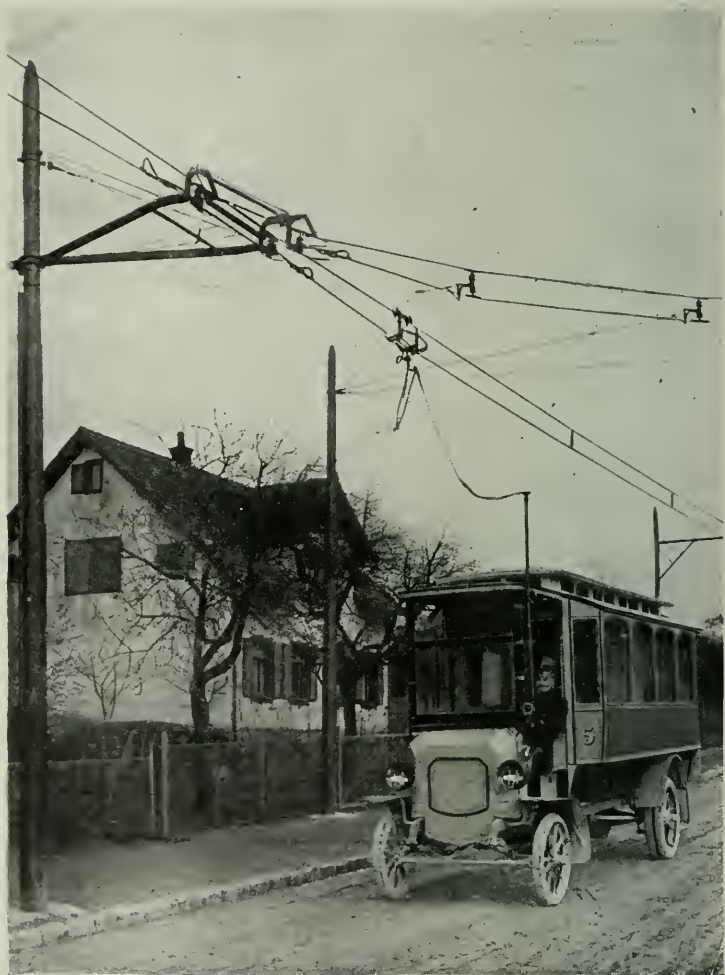


FIG. 15.—“ LLOYD-KÖHLER ” VEHICLE AND OVERHEAD CONSTRUCTION.

imum authorised speed on the first two routes mentioned is $12\frac{1}{2}$ and $15\frac{1}{2}$ miles per hour respectively but the mean speed from end to end only averages $9\frac{1}{2}$ and 10 miles per hour.

The “ Filovia ” system is in use in Italy to a large extent, there being as already stated over 50 miles installed, all of which have been constructed by the Società Trazione Elettrica. This growth of the system, which was first installed in 1902, is doubtless largely due to the Government, which grants a subsidy up to £60 per annum for each mile of line equipped with

railless traction in districts not already provided with tramway or railway services. Further than this, in the case of the Intelvi Valley line from Lake Como to St. Fedele the Government pay a subsidy of £320 per annum for the carriage of the mails.

In this system the double overhead wires are placed side by side at a distance of $13\frac{1}{2}$ in. apart and 17 or 18 ft. above the ground, but the current is collected by a special four-wheeled truck making contact with the under side of the wires and carried at the end of a single boom of the rigid type fixed on top of the vehicles, and which contains the twin cables. The upward pressure of the collector on the wires is about 12 lb., while a ball-and-socket joint between the boom and the collector affords the necessary flexibility for sideway movement of the cars, which can run at a distance of 10 ft. from the wires. A speed of 20 miles per hour or more can be obtained with safety.

The cars are of the single-deck type, generally seating 20 to 24 passengers and weighing 2 tons 13 cwt. when empty and 4 tons loaded. They are fitted with two motors, one to each wheel; to meet the conditions obtaining in this country, they are of 15 b.h.p. each at 525 volts, and drive through a flexible coupling, spur reduction gear and a roller chain. The gear ratio from the motors to road driving wheels is 12.75 to 1. The speed attained is 18 the miles per hour on the level and about half of this on a gradient of 1 in 20. The current varies in different schemes from 500 to 650 volts. On the Ivrea Cuorgne line, $15\frac{1}{2}$ miles long, the generating station is located half-way along the route and the whole length is fed with current at 650 volts through the trolley wire. The controller is placed in a horizontal position under the driver's platform; it is actuated by pedal levers and fitted with magnetic blow-out and gives five speeds forward and reverse. The cars are fitted with an electric brake and two mechanical brakes, one acting by expansion on drums on the inside of the wheels and controlled by a hand lever, and the other acting on the motor countershafts and controlled by a foot pedal. On the Lake Como line, which has an average gradient of 1 in $16\frac{1}{2}$ over the length of $5\frac{1}{2}$ miles, with a maximum of 1 in 7.7, and where the whole of the downward journey is done without using any current, the brakes are cooled by water carried in a tank on the roof of the vehicles. The wheels are of steel, running in ball bearings and fitted with single solid rubber tyres. In some cases the lines are fed by an overhead cable carried on the same poles as support the trolley wires. The English representatives of this system are Messrs. Watlington & Co., of Moorgate Station Chambers, London, E.C.

The "R.E.T." system differs considerably from all the foreign systems just described. It was designed by the Railless Electric Traction Company, now the R.E.T. Construction Company, specially to suit British conditions, and was first

tried on the experimental length at Hendon in September, 1909. In an improved form it has been installed by this company upon the only two systems at present working in this country, namely, Leeds and Bradford, and is now being installed at Dundee and Rotherham.

The positive and negative overhead wires are placed parallel about $13\frac{1}{2}$ ins. apart and 21 ft. above the surface of the ground. Four wires are provided so that a continuous service can be maintained in each direction. At Leeds they are all placed close to each other and suspended from 18 ft. bracket arms; the two inside wires being positive and the two outer negative. The Bradford overhead work is on the span-wire system. The cars are fitted with double trolley booms of the under-running type, and placed side by side as shown in Fig. 16, Plate II. The weight in the most modern type is about 3 cwt. These trolleys permit the car to deviate within a width of 15 ft. on each side of the centre of the wires, as measured to the centre of the vehicle, but longer booms can be made if desired. The cars run without difficulty with the trolley boom at right angles to the direction in which the car is travelling. The tension in the springs is rather lower than usual in tramway practice and gives an upward pressure of about 12 lb., this being all that is necessary, because besides the usual raising springs there are additional springs working in a horizontal plane and controlling the pivot of the trolley base so as to relieve the trolley wheels of excessive side pressure and to ensure the trolley head remaining in contact with the wires. Each trolley boom is capable of swinging quite independently of the other. The facility with which the cars can be run in and out of the traffic and the rapid swerves across the road which they can make at high speed without displacing the trolley are remarkable and one would hardly expect such perfect flexibility unless they had actually seen the system at work. The only difficulty which has been experienced since the lines were opened was at the terminal circles during the first few days and before the drivers had become accustomed to turning the cars on a curve approximating to that of the overhead work. Fig. 17, Plate II., which is taken from the *Light Railway and Tramway Journal*, shows a car drawn up to receive passengers on the opposite side of the road to that on which the poles are erected.

The route at Leeds is $3\frac{3}{4}$ miles long, going from the City Square to Upper Moor Top at Farnley. The fare for the whole distance was originally 3d. but is now 2d., and the journey averages 24 minutes. At the City terminus the cars pass round a triangular block of buildings and at the other end the overhead wires at the junction of two cross roads form a circle around which the cars pass. For the first seven-eighths of a mile the trolley omnibuses pass along a road in which the trams run

EM AT LEED

PLATE II.





FIG. 17.—LEEDS CAR DRAWN UP AT SIDE OF ROAD.



FIG. 24.—SIDE VIEW OF BRADFORD CAR.



FIG. 16.—R.E.T. CONSTRUCTION
 COMPANY'S DOUBLE TROLLEY.

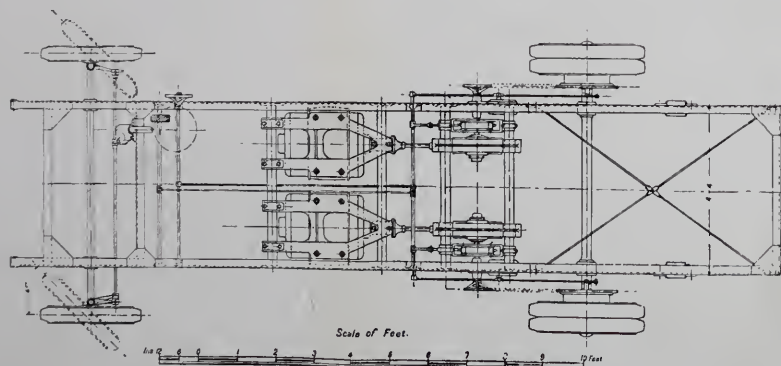


Fig. 19.—Plan of Chassis of Railless Trolley Car.

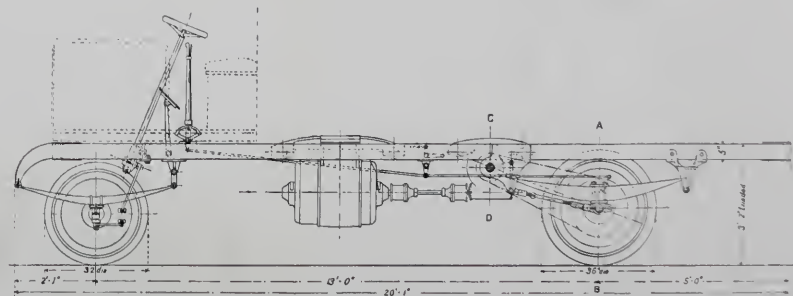


FIG. 19.—SIDE ELEVATION OF R.E.T. CHASSIS.

and on this section the omnibuses use the same positive wires as the tramway cars. The omnibuses are fitted with a skate hinged to the chassis, and consisting of a rail cleaner, a brush, a guide wheel to fit the groove of the tram rail, and a copper contact piece, by means of which after the negative trolley has been lowered, the return current can be conveyed to the tramrails when it is desired to run the omnibuses along a tram route where there is no negative wire. In this way the omnibuses, using one boom only, can run over any part of the tramway system. The skate allows a maximum deviation of 5ft. on either side of the rail into which it may be fitted. The omnibuses pass under four railway bridges varying in height from 14ft. 9in. to 16ft.

The route at Bradford is $1\frac{1}{4}$ miles long from Laisterdyke to Dudley Hill through a thickly populated district and connecting at each end with an existing tramway service. The fare for the whole distance is 1d. and the journey occupies 10 minutes. The cars use the tramway depot at Thornbury; the omnibus wires being suspended from the bracket arms carrying the tramway wires between the depot and Laisterdyke. The overhead wires form a circular curve at the Dudley Hill end of the route, but at Laisterdyke the wires form an open-angled triangle at the intersection of a branch road. When the car arrives at the terminus it travels round one side of the triangle into the side road, then the trolley booms are changed on to the other side of the triangle and the car backs into the main road, where the trolley booms are again moved on to the wires forming the third side of the triangle, when it is ready to commence the return journey.

The motors consist of two Siemens interpolar traction motors with shunted fields, each having a capacity of 20 h.p. at 525 volts and a speed of 1,050 revolutions per minute; being equivalent to an omnibus speed of 10 miles per hour. They drive, by means of a propeller shaft and worm gearing, on to countershafts parallel with the rear axle, from whence the power is transmitted to the wheels through a case-hardened sprocket wheel and roller chain enclosed in a dust-proof case. Each motor is arranged to drive one rear wheel. The controller is of the Siemens series-parallel magnetic blow-out type provided with special arrangements for cutting out either motor as desired, but having no provision for rheostatic braking. The main barrel has five running positions, namely:—

- (1) Motors in series, full field, resistance all out.
- (2) " " " field shunted 50 per cent.
- (3) Motors in parallel, full field, resistance all out.
- (4) " " " field shunted 25 per cent.
- (5) " " " " " 50 per cent.

There is one important provision in the design of the cars which may be pointed out, and that is the precaution taken to nullify the effect of any leakage of current which may occur in some unexpected manner. In a tramcar all metallic parts are bonded to each other and to the underframe, whence contact is made through the wheels to the rails so that the whole vehicle is maintained at the same potential as the rails ; but in a trolley omnibus this cannot be done, as the rubber tyres effectually insulate the vehicle from earth, therefore all handrails, etc., require to be specially insulated. In this connection it may be mentioned that the Railless Electric Traction Company have patented a system of three overhead wires (two positive and one negative) and special trolley head which ensures that the car can be kept in electrical connection with the negative wire, and the wheel selected for the negative connection cannot come in contact with the positive wire.

The chassis is shown in Figs. 18 and 19, Plate II. The wheels are 32in. and 36in. diameter, of artillery pattern, and fitted with solid rubber tyres, single on the steering wheels and twin on the rear wheels. The wheel base is 13ft., and width between centres of rear wheels 6ft. 3in.

There are two mechanical brakes, one operated by a foot pedal and acting upon a drum on the countershaft and the other operated either by foot pedal or hand lever, acting upon drums on the rear wheels, with a ratchet arrangement for holding the brake on when desired.

The car bodies, which were built by Hurst, Nelson and Co., have a seating capacity for 28 persons and are of single-deck type. They are illustrated in Figs. 20 to 23, which have been prepared by the author, by kind permission, from illustrations which appeared in the *Tramway and Railway World*. The entrance to the Bradford cars is from the rear, while admission is gained to the Leeds cars by a door from the driving platform. This latter was to obviate the necessity for a conductor, but the service has proved so popular that it has been found desirable to carry a man to collect the fares, etc. The seats are arranged so that the passengers face in the direction they are travelling. The driver's platform is enclosed and provided with adjustable side windows and hinged wind screens, while the space enclosed by the dash is watertight and affords room for passengers' luggage. The weight of the latest type of car, unloaded, is 3 tons 12 cwt., and when loaded, about 5 tons. They are 20ft. 3in. long, and have an overall width of 7ft. The height to the driver's platform is 3ft. 6in. and to the top of the vehicle 10ft. 8in. The Bradford cars have been fitted with shock absorbers, consisting of four spiral springs under the body of the car, one at each corner. A side view of a Bradford car is shown in Fig. 24, Plate II. The current consumption on the Leeds route

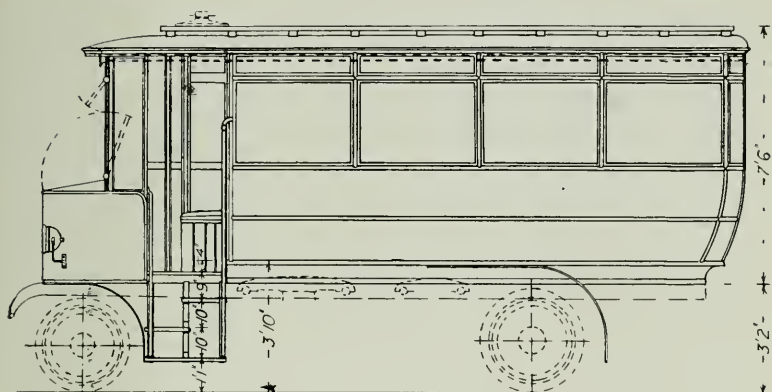


FIG. 20. SIDE ELEVATION OF RAILLESS TROLLEY CAR

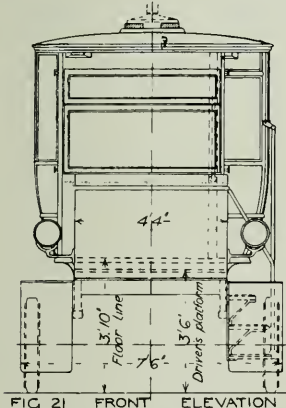


FIG 21 FRONT ELEVATION

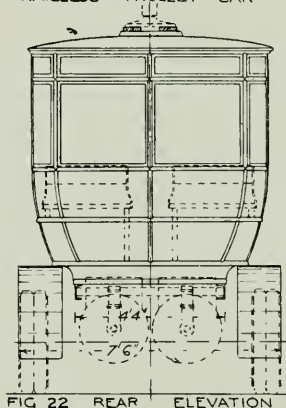


FIG 22 REAR ELEVATION

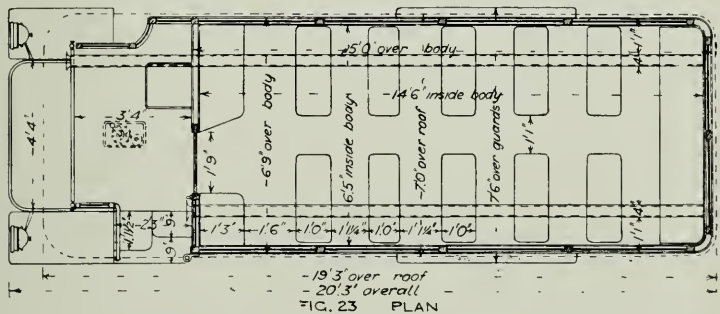


FIG. 23 PLAN

FIGS. 20 TO 23.—ELEVATIONS AND PLAN OF A LEEDS CAR.

is 0·87 unit per car mile, while on the Bradford route, which has steeper gradients, it is 0·95 unit per car mile including all transmission losses.

As regards capital cost there is, as would be expected, considerable variation in the figures.

The first eight systems installed by the Mercedes-Stoll Company up to January, 1911, aggregate a route length of 17·26 miles and are worked by 30 cars each capable of seating from 18 to 24 passengers. The total capital invested in these lines amounts to £48,500, being at the rate of £2,800 per mile, or £1,600 per vehicle, but it must be remembered that should the traffic increase, additional vehicles can be put on the road for a further capital expenditure of say £600 each.

The total capital cost of the line from Ludwigsburg to Württemberg, working on the Lloyd-Köhler system, amounted to £16,000, being at the rate of £1,843 per mile, or £2,000 per passenger vehicle. The company estimates the cost of a scheme as follows:—Overhead work, £900 to £1,100 per mile; cars, £900 to £975 each; trailers £340 to £380 each; garage and workshop, £400 to £700.

The estimated capital cost of the proposed scheme at Aberdeen for a route 1 mile 33 yards long is £3,050, made up as follows:

1 mile 33 yards of route at £1,227 per		
mile	=	1,250
2 cars at £700 each	=	1,400
Cost of Provisional Order	=	400
		£3,050

The capital cost is therefore equal to £3,000 per mile of route or £1,525 per vehicle.

The estimated cost of construction at Nuneaton is £9,000 for a route of $3\frac{1}{4}$ miles and 4 cars, being equal to £2,400 per mile of route or £2,250 per vehicle running.

A circular railless traction route of nine miles at Krugersdorp is estimated to cost £50,000, being at the rate of £5,555 per mile including cars and incidental expenses.

The capital expended on the 5-mile route at Drammen was £8,000, being equivalent to £1,600 per mile. The overhead wires are carried on span wires between the houses and where this method is not convenient then on timber masts with side brackets.

The cost of $3\frac{1}{4}$ miles at Ramsbottom is estimated at about £9,250, being at the rate of £2,846 per mile including overhead equipment, three cars, depots, shelters and incidental expenses, against £28,000 (£8,600 per mile) for a system of electric tramways. Including the generating station, the cost will be £16,150 which is equivalent to £4,969 per mile of route.

At Stockport the railless traction scheme is estimated to

cost £11,000 (of which £7,000 is for the overhead equipment) against £20,000 or £25,000 for electric tramways.

In some of the schemes abroad the overhead work, including cables, has been constructed for as low a figure as £700 to £750 per mile; timber posts and bracket arms being employed. It would be, however, a great mistake, unless in very exceptional circumstances, to put up in this country such flimsy work as this cost represents and, further, it is very doubtful if such work would receive official sanction. A small addition to the capital cost involves only an infinitesimal increase in the annual cost for interest and repayment of principal, but the depreciation and the cost of maintenance would be very heavy, so much so, perhaps, as to render the scheme unremunerative. This point was thoroughly discussed in connection with tramway construction, and the same arguments apply to this system. The cost of the overhead work at Bradford is given as £1,684 per mile and at Leeds £1,240 per mile, while the accepted tender for the work at Dundee is at the rate of approximately £1,000 per mile. If a cheap construction is adopted, its life will probably be short so that it would not last long enough to be utilised subsequently for a tramway service. If by any reason a railless route is, or becomes, unremunerative it is, of course, possible to take down the overhead work, remove the cables and refix the materials on another route, but the cost of doing so is very great and the proposition should not be lightly entered upon; hence the necessity for good judgment in the initial installation.

Judged from the standpoint of seating capacity the price of railless vehicles is high, due perhaps to some extent to the high standard of luxury we have been trained to expect in public vehicles, and to the small number of them required at present. The price charged for a Railless Electric Traction Company's omnibus having a seating capacity for 16 passengers is £600, for 24 passengers £675, for 28 passengers £700, and for 30 passengers £750. The California open-type cars, seating 16 passengers, weigh about $1\frac{1}{2}$ tons, unloaded, and cost £520. The cost of an omnibus of the Mercedes-Stoll type seating from 18 to 24 passengers is about £600. The cost of a well finished vehicle to seat 24 and mounted on a "Brush" chassis as shown in Figs. 18 to 20 is approximately £750.

The cost of obtaining the necessary Parliamentary powers depends entirely upon the amount of opposition offered to the Bill; it might vary between say £400 and £5,000. Reasonable periods to allow for the repayment of the cost of installation would be as follows. The cost of the Bill, 5 years; vehicles, 10 to 15 years; overhead equipment and passenger street shelters, 20 to 30 years; lands, buildings and underground caques, 40 years.

Ample data exists as to the cost of running railless schemes

abroad, but the extent to which similar results will be realised in this country is more or less a matter of conjecture, as the only figures available are those relating to Leeds and Bradford and, interesting and useful though they are, it must not be forgotten that they cover only a short period.

The cost of working by the Max-Schiemann system on the line at Ahrweiler, on the Rhine, was 5·38d. per car mile made up as follows :—

	d.
Management and wages	2·86
Electricity (576 watt-hours per car mile) ..	0·95
Tyres	0·66
Maintenance of line and vehicles	0·25
Stores	0·27
Insurance, sick fund, etc.	0·39
Total in pence per car mile	5·38

It should be noted, however, that the rear wheels have steel tyres so that the tyre maintenance rate only covers the front wheels.

The receipts per car mile on the first eight lines constructed by the Mercedes-Stoll Company, to which reference has previously been made, vary from 5·6d. to 8·0d., the fares charged being approximately 1½d. to 2d. per mile. The average number of passengers carried per car mile is 3·53. There is one small system at Judenburg, where the receipts amount to 10·75d., with working expenses at the rate of 4·8d. per car mile, showing a profit of 5·95d. per car mile. This is exceptional, the line being only 1·24 miles long and worked by one car, seating 18 persons. The maximum gradient on this system is 1 in 6·66 whereas the maximum gradient in any of the other systems is 1 in 11. The cost of working varies from 4·16d. to 5·0d. per car mile, the profit ranging from 0·8d. to 3·52d. per car mile, but this does not include interest and sinking fund. It should be pointed out that the price paid for the current is high, and varies from 1½d. to 3d. per unit.

The following figures show the result of working up to September, 1911, on the Wiedling line, near Vienna, which is 2·3 miles long, has a maximum gradient of 1 in 14·3, was opened for traffic in May, 1908, and is worked by 5 cars, each seating 22 passengers.

	£
The capital invested is	£7,000
Car miles run	194,783
Total passengers carried	796,514
Receipts per car mile	8·00d.
Expenses per car mile :—	
	d.
Management and wages	1·56
Electricity	1·38
Tyres	0·69

	d.
Repairs, including maintenance of vehicles, replacements, etc.	1·19
Insurance and sick fund	0·18

Total cost per car mile including everything except interest on capital, and sinking fund 5·00d.

The price paid for electricity is 2·60d. per kilowatt hour. The margin between receipts and running expenses available for interest on capital, depreciation, etc. is 3d. per car mile which is equivalent to £2,434 since the line was opened, or approximately £1,000 per annum, or say 14 per cent. upon the capital invested.

The Lloyd-Köhler Company state that the cost of sinking fund, depreciation, maintenance, electric current, tyres, management, wages, etc., varies from 4½d. to 7¾d. per car mile. This allows a somewhat wide margin, but the actual result of working on the Ludwigsburg route for its first complete year, namely 1911, is set out hereunder.

Expenses per car mile :—	d.
Management and wages	1·43
Electricity	1·13
Tyres	0·95
Maintenance of vehicles	0·76
„ „ line	0·09
Tickets, uniforms, etc.	0·44
Insurance, etc.	0·15

Total cost in pence per car mile including everything except interest on capital, and sinking fund 4·95d.

The receipts per car mile were 7·03d. so that the margin between receipts and running expenses available for interest on the £16,000 capital, depreciation etc., is 2·08d. per car mile.

The cost of working for the year 1908, at Spezia, Italy, where the Filovia system is in operation on a route 4½ miles long and where the cars seat 18 persons, has been given as 5·645d. per car mile, made up as follows :—

	d.
Management and office expenses	0·594
Wages	1·400
Electric current (564 watt-hours per car mile)	0·415
Tyres	2·160
Maintenance of cars and line	1·076

Total in pence per car mile 5·645

The fares charged average 1d. for about $1\frac{1}{8}$ miles. The cost of tyres is high, due to the road surface being always in a very bad condition.

Another set of figures for this system, and relating more to an average over several routes, are :—

	d.
Management, salaries and wages	1·6
Electric current (485 watt-hours per car mile at $1\frac{1}{2}$ d. per kilowatt-hour) ..	0·8
Tyres	1·7
Maintenance of cars	0·7
„ „ overhead line	0·2
Total in pence per car mile	5·0

The receipts at Leeds (R.E.T. system) have been at the rate of 10·75d. per car mile while the running costs are 4·50d., and the fixed charges, including interest, sinking fund and depreciation 1·80d., making a total of 6·30d. per car mile and showing a net profit of 4·45d. per car mile. The receipts at Bradford have been 8·25d. per car mile and the costs 6·0d. showing a profit of 2·25d.

Strict caution has characterised the estimates of the cost of working and of the probable receipts for schemes projected in this country ; the one generally being taken as approximately balancing the other, with very little margin for repayment of capital charges. The point is, of course, that the proposed routes are very thinly populated at present, but it is expected that the provision of travelling facilities will encourage the development of the districts through which the omnibuses pass, and the systems will ultimately prove fully remunerative.

The number of passengers carried per car mile is generally low in railless schemes, the principal reason being that only single-deck cars are used, having a maximum possible seating capacity of about 28. These are amply large for ordinary working but during the rush hours the capacity is too limited for the number then carried to raise the average to any considerable extent ; consequently the margin between receipts and working expenses will in many cases be small, and very careful management will be necessary to ensure financial success. The general passenger fares proposed to be authorised in the various Bills before Parliament are at the rate of 2d. per mile. To a certain extent some improvement in the returns might be effected by putting on extra vehicles for an hour or so when required but it involves capital lying idle during a great part of each day. Another objection to single-deck vehicles is the absence of any accommodation for smokers, but this could be overcome by forming two compartments as is proposed in the Rotherham cars, or by constructing an open platform at one end of the omnibus, as is done in some of the vehicles on

the Continent. The Board of Trade have not hitherto favoured double-deck vehicles, but in the Hove Corporation Bill, and doubtless in others, it is sought to obtain powers to run such vehicles.

Trailer cars are used to a considerable extent on the Continent in connection with trackless systems; but although the London County Council are seeking powers, during the current session, to run trailers with the tramcars it is very doubtful whether such a course would meet with any support in a trolley omnibus scheme, at least at the present time. With trailers a tracking arrangement should be fitted so that they accurately follow all curves and windings of the tractor.

It is now generally conceded that owing to the smoother running of an electrically driven vehicle the tyres wear better in such case than on a petrol-driven vehicle of equal weight. The Railless Electric Traction Company state that the tyres on their vehicles will be maintained in perpetuity at a charge of 1d. to 2d. per car mile, dependent upon the route and the nature of the road surfaces. Alternatively a set of new tyres would cost from £65 to £95 respectively. The author is informed that one of the largest tyre companies has undertaken to maintain the tyres on any of the Trackless Trolley Company's omnibuses (Mercedes-Stoll system) running on reasonably good roads at the rate of 1d. per car mile. On the Kalksburg line, 2.4 miles long, worked on this system, and having a maximum gradient of only 1 in 50, it appears from the report of the Superintendent that it has only been necessary to replace the rear tyres on two of the four 22-passenger cars after having run 28,000 and 24,000 miles respectively. The tyres on the other two cars were still in good condition after having run 22,000 and 17,000 miles respectively. The Lloyd-Köhler Company guarantee their tyres to run 12,500 miles but the average distance actually run by the tyres before renewal has been over 15,500 miles.

It has been mooted by some District Councils that whereas the construction of a tramway reduces the cost of maintenance of a road, a railless traction scheme would considerably increase the cost. Of course if a private tramway company is called upon to maintain a width of say 16ft. out of a 30ft. road, it does not leave much for the Local Authority, and it is obvious that the cost to the rates is reduced, but the total cost is not usually affected to any appreciable extent. It is well known that the cost of maintaining country roads has considerably increased since the advent of motor cars, the reason being that the common method of construction was unsuitable for such traffic. Now instead of prohibiting the use of motors, the roads in all parts of the country are being formed to carry them; and any road which can do this satisfactorily can also carry the light trolley omnibuses without further addition to the cost of maintenance. It is reported that certain payments for the user of the road

have been demanded in some places, as for instance $\frac{3}{4}$ d. per car mile in Rotherham by the West Riding County Council, $\frac{1}{2}$ d. per car mile in Brighton by the Sussex County Council, while at Keighley the Rural District Council are asking for payment by the Town Council, and in connection with the Stockport scheme the Marple U.D.C. suggest that $\frac{1}{2}$ d. per car mile should be allocated to the respective highway authorities for the maintenance of the roads. This point was, however, fought very hard in the Aberdare Bill in both Houses of Parliament, and in neither case would the Committee insert a clause requiring payment for the use of the roads. The petrol tax works out at about $\frac{3}{16}$ d. per mile in the case of motor buses, which are very much heavier vehicles.

It may be suggested that the author has not compared to any great extent the relative costs of electric tramways, motor omnibuses and trolley omnibuses, but he must plead in extenuation, the exigencies of time and the space available in the Transactions of the Society. This, however, need not prevent the champions of the respective systems who may be present this evening from advocating their cause in any possible way. Briefly it may be said that the principal rivalry is between the motor omnibus and the trolley omnibus, because in many cases financial considerations alone would prohibit the construction of tramways. The main points to consider are the capital cost of installation, the cost of working and maintenance, reliability, and the public convenience. The author will content himself by giving utterance to the safe, and by no means novel, statement that there is no one method of traction that can be adopted with success under all conceivable circumstances. Each has its advantages, but which is the best to adopt in any particular case can only be arrived at after a careful investigation of all local conditions and with an intimate knowledge of the possibilities of the various systems; and, further, it by no means follows that the results obtained in one town will prevail in another. This system can be installed for a capital expenditure of about one-third to one-fifth of that required in the case of an ordinary overhead tramway system; and while the cost of maintenance of the road will not be unduly increased, and will continue more or less constant from year to year, it must not be forgotten that a tramway track requires entire reconstruction from time to time. On the other hand the cost of maintenance of the vehicles with their rubber tyres would be higher than in the case of tramcars, and more electrical current would be consumed per passenger carried.

The author begs leave to acknowledge the loan of the blocks for some of the illustrations and the further assistance he has derived in the preparation of this paper from the information supplied to him by the R.E.T. Construction Company, the

Trackless Trolley, Ltd., the Brush Electrical Engineering Co., Messrs. Watlington & Co., and the several foreign traction companies, and also from the descriptive and well illustrated articles which have appeared from time to time in the *Tramway and Railway World*.

The **President** moved a hearty vote of thanks to Mr. Adams for his excellent and exhaustive paper. He (the President) had no idea that the railless system was in such extensive use, for he had not travelled much on the Continent in recent years.

DISCUSSION.

The Secretary read a communication from **Mr. D. Harrop** (Manchester Corporation Tramways) as follows :—

“ The most interesting feature to my mind, from an engineering point of view, is the very novel Mercedes-Stoll hub motor, with its large number of field poles (10 to 12) keyed on to a stationary axle, the motor revolving round them. At first sight it would not appear theoretically possible to gain a high efficiency out of such a small speed motor, but the characteristic curves show the efficiency at the road surface to be well over 80%, and at the average working current an efficiency of 87% is obtained, this being, if anything, a trifle higher than is usually obtained from the ordinary traction motor, *i.e.*, exclusive of gearing losses. The design of this motor has been very cleverly thought out, and, as the absence of gearing makes it necessary for the motor to supply the whole of the torque, heavy armature current and high field strength will be required, hence the large number of field poles and the four brushes which are used on the radial commutator.

“ The flexibility of this system and the Lloyd-Köhler system certainly give them an advantage over their rivals on purely trackless lines ; but I agree with the author that the double pole under-running trolley booms are necessary for home systems. The method used by the Lloyd-Köhler and Schiemann systems of obtaining acceleration by shunting some of the field current is interesting, and the use of interpoles on their motors would appear to be very necessary to diminish armature reaction due to this weakened field. On page 40 the author mentions the possibility of a trackless line developing to the paying limit of the ordinary tramway. This, I believe, actually happened on the Monheim-Langenfeld line.

“ **SERIES-PARALLEL CONTROL.** — As with these trackless systems there is not nearly the same amount of stopping and starting as on ordinary city tramway routes, it does not appear as though this form of control were so necessary. Under these circumstances the use of one motor equipment might prove quite

sufficient for the purpose, and thus assist in the lowering of the capital and maintenance charges.

"ELECTROLYSIS.—On certain systems, notably the Lloyd-Köhler, the negative wire is earthed out at various points on the route. This can be done, of course, by earth plates bonded to the poles. But the present Board of Trade 'Rail Drop' limit for tramways is 7 volts, and as the negative trolley wire has a resistance of, approximately, 16 times that of 4 tramway rails in parallel usually acting as a return, the voltage drop in the negative wire might be excessive, and the leakage currents might possibly cause electrolytic damage to gas mains, water pipes, &c., in immediate contiguity to the earth plates.

"A standard type of body (within limits) would not be a bad idea, though each manager seems to want something entirely different from the others, and one firm has already, I believe, made eighteen different types of body to suit their customers. This is bound to increase the cost of the vehicles.

"Are not the Max-Schiemann and R.E.T. systems practically similar? I was given to understand the latter firm were acting for the former in this country."

Mr. R. W. A. Brewer said that there was a point which was most important in connection with the problem of the increase of traffic in rapidly growing districts. They could all see how the presence of tram rails upon a road, however wide, enormously decreased the carrying capacity of the road. Attention was drawn, when the question of the tramway traffic of the London County Council trams was brought up the other day, to the fact that, if the trams had not been owned by the London County Council, they would probably disappear rapidly from the London streets. That was perfectly true. The trackless system thus got behind one of the very great difficulties which had been experienced for a long time, and could supply a system of passenger transport with a central generating station without occasioning the obstruction already referred to.

The paper had drawn attention to the fact that the railless trolley system enabled vehicles to be manipulated very readily with but very little obstruction to the other traffic of the road. That was, of course, a most important point, but there were certain other points which a few years ago appeared to be very attractive before the rapid development of the motor omnibus took place. He thought that some of the most attractive features which existed some three or four years ago were at the present time scarcely of such great importance. When they looked at the development which had taken place in the motor omnibus, it was impossible to close their eyes to the fact that the modern well-constructed, well-designed motor omnibus had all the important features which the railless trolley system had ;

and it had many other features which would be sure to strike home to those persons who were considering a system of transport either for goods or for passengers.

A point which he had not noticed as the paper was read was the weight of any particular vehicle. The author had said in various cases that the weight of the trolley vehicle was small, but he did not see the particulars given as to weight of the various parts. He thought that the first occurrence of the mention of weight was on page 39 of the paper, where the author said something about the weight of the engine in a petrol-driven 'bus, and referred to the weight as being considerable, and the elimination of that weight as being a great advantage in the trackless system. The weight of the engine was certainly notable, but when they had a 'bus weighing five tons or upwards, the exchange, as it were, of the weight of the electric motor for a petrol motor was not a very serious matter. Of course, there was the weight of the fuel, but against that there was the weight of the controller and the resistances and various other appurtenances which were always necessary in the electrically driven vehicle.

On a later page there appeared a diagram showing that a steering wheel was used in the ordinary way, and there was a controller for the man's other hand. But it would appear to him that, if the man was approaching other traffic or conducting any sort of evolution, he would be doing so at considerable disadvantage, because he must have control of the power with one hand, and he had only one free hand to do any particular steering feat. The ordinary omnibus driver controlled the power with his feet.

The author had given some very valuable and interesting figures on the question of cost ; but he believed that the meeting would agree with him that those figures bore out his (Mr. Brewer's) argument in favour of the motor 'bus or the self-propelled 'bus. There was a table on page 58 in which the cost of two cars was stated to be £700 each. That figure bore a very close relation to the cost of a motor 'bus. At the top of the table the cost of the track was given, and was as much as the cost of the vehicles, but, of course, that same track would accommodate more than the vehicles which were upon it. But throughout the whole of the figures they would find that the cost of the overhead system bore a very large proportion to the total cost of the whole scheme. In the Stockport system, for instance, at the foot of the same page, there was a figure of £11,000, of which £7,000 was for the overhead equipment. He should like to know how much the power plant cost, and how much the vehicles cost, because there was only £4,000 left for the working part of the whole system. That £4,000 would only represent the cost of petrol-driven motor omnibuses to give equal facilities, plus garage charges, which would be a small figure. Throughout the rest of the figures they

found that the cost of cars was from £900 to £975 apiece. These did not bear very favourable comparison with the cost of a modern petrol-driven motor omnibus. In a case of this sort it must be borne in mind that there were two staffs of employees in charge. In the self-contained system, of course, the road staff was the only one except the ordinary garage staff.

The effective and satisfactory commercial result which could be obtained from a system of this sort depended very largely upon the cost of tyres. Within reasonable limits the tyre cost made all the difference between a concern paying or not paying. In many cases there was only a penny or three-halfpence a car mile between success and failure. The cost of india-rubber tyres per car mile varied, according to the paper, from 0.69d. to 0.95d. There was a difference between the figures which required some explanation. Personally, he thought the cost of 0.69d. was very low.

Mr. A. Winter Gray said he had been invited to draw attention to the fact that the railless traction system had quite recently been considered by that influential body the County Councils' Association.

At the meeting of the Executive Council of the Association, held on Wednesday, February 28th, the Highways Committee submitted a lengthy report upon all the matters affecting highways and vehicles which had been brought before the Association since 1902. With reference to the question of railless traction, the Committee recommended that it should be in the power of the road authority to refuse its consent to the introduction of trackless trolleys over its roads, subject to provisions for preventing unreasonable refusal when the application related to roads in the district of more than one road authority, and when the promoters had given satisfactory security for bearing any additional cost of the maintenance of the roads due to traffic brought on to them by trackless trolleys. Further, the Committee expressed the opinion that among the conditions which might properly be required by a road authority were the following:—

(a) That, where such powers were granted, promoters should be obliged to contribute towards the cost of maintenance of the roads, either in the form of a car mileage rate, or rent, or capital sum, or in more than one of these.

(b) That the road authority should have power to control the weight of the cars, and, if necessary, to prohibit cars of excessive weight.

(c) That strict regulations should be laid down as to the dimensions and material of tyres, and that there should be a periodical revision of such regulations.

(d) That the traffic should be subject to general regulations made by the road authority.

He entertained the hope that Parliament and municipal authorities would hesitate before imposing onerous provisions which would tend to retard the progress and development of an industry which, although in its infancy, would undoubtedly afford increased travelling facilities to residents in urban and rural districts throughout the country. He thought the conditions quoted were worthy of careful consideration, and might influence the discussion of Mr. Adams's valuable paper.

Mr. J. F. Jodrell Reynolds said that he gathered from the paper that at present only two short lines were at work on the trolley vehicle system in this country, and that therefore the amount of information as to constructional and working costs was necessarily limited. There was one point upon which he thought further information would be acceptable, namely, longitudinal sections of the Leeds and the Bradford routes, showing the principal gradients, and also the direction of the greatest load should there be any noticeable variation.

He thought that the name under which the system had been introduced was, perhaps, a little unfortunate. The terms "trackless trolley" or "railless electric traction" did not convey very much, being of a negative rather than a positive character; he much preferred the author's own expression, "trolley vehicle."

He thought it would be agreed that the trolley vehicle system had many points to recommend it as compared with tramways, and was—at least in some situations—superior, for unless a roadway, with a double line of tramway, was at least 15ft. wider than was required to accommodate the ordinary vehicular traffic, there was not only delay to the other vehicles, but the tramway could hardly do justice to itself. This would not apply to the trolley vehicle, because it was able to take its place with other vehicles and also to draw up to the kerb for taking up and setting down passengers.

In designing any trolley vehicle system it certainly appeared to be an advantage—unless the route was short or only one vehicle was to be used—that the overhead wires should be duplicated. The times given for exchanging the trolleys, namely, 8 seconds, as given on page 44, and 15 to 20 seconds, on page 49, for different systems, could hardly include the time taken in slowing down and manœuvring for position in order that the trolleys might be changed over. The further fact that the exchange must take place in the middle of the road must certainly cause additional stoppage to other traffic. If it was not considered necessary to duplicate the overhead wires throughout the whole length of the route, it might be possible to arrange for a long loop to be placed at points where there was any chance of trolley vehicles having to pass.

It was satisfactory to find that the claim made by local authorities for a rate for extraordinary traffic was being successfully resisted, because, although such rates were quite fair in the case of a private individual, or even a private company, for using a road for extraordinary purposes for short periods during, say, the construction of a railway, or for the erection of buildings, it was hardly fair that such a rate should be levied upon a company which provided facilities for the travelling public.

Mr. Horace Boot said that when he read a paper before the Institution of Municipal Engineers on the 16th December, 1911, the author of the present paper criticised him severely, and was then an opponent of the trackless trolley system. To-night he welcomed the author on coming into the fold as an enthusiast on the trackless trolley. He (Mr. Boot) had personally given attention to the subject since the year 1903, when he designed the first system for a very large area in and around Tunbridge Wells. He was surprised to find how superior to the ordinary motor 'buses the trackless trolley was for country districts. On almost every point it had its advantages.

The amount of capital lost in the motor 'bus industry could only be realised when one reckoned all the capital subscribed during the last five years and found out what had been wasted. Such a thing had not happened with the trackless trolley. Almost the first line which was put down on the Continent proved a financial as well as a technical success. There had been small improvements and the development had been slow, but there was no doubt that the advantages of the trackless trolley over the motor 'bus for country districts with bad roads and severe gradients, could not be over-estimated. A motor 'bus had to carry the maximum horse-power required for the work to be done, and during 75% of the time it ran with only 25% of its maximum load. With the electric motor the conditions were entirely altered. It had not to carry 40, 45, or 50 horse-power, as even a London motor 'bus had to do where there were good roads and no hills. To suggest railless traction for London was absurd. Why compare the trolley omnibus with the figures of the London General Omnibus Co.? The proper comparison would be with the figures for rural or country omnibuses. For instance, take the cost of running motor omnibuses at Keighley. It would be found that the cost was something like 8d.; the figure for London would be doubled, and other costs would be higher. He did not want any engineer to take it for granted that the motor omnibus, although suitable for London, was suitable at present for rural districts. His experience was that it was not.

The question of Provisional Orders was mentioned in the paper. All electrical engineers knew that the electrical engineering profession had suffered very much from over-legislation, and,

if Parliament could do anything to lighten the burden it would indeed be bringing about an advantage. In the early days of electric lighting the cost of obtaining powers would often run into four figures ; but to-day an unopposed Provisional Order could be obtained for about £120. He did not see why Provisional Orders should not be granted for railless traction.

As regarded payment towards the cost of maintaining the roads, to a certain extent that payment was perhaps fair ; but he would point out to those people who were thinking of levying such a payment that there was no such tax beyond the petrol tax made on motor omnibuses or on private cars, nor would there be any tax made, provided omnibuses of a different nature did not require an Act of Parliament.

Capital outlay was a very important question. The figures which he put forward were figures with which he thought Mr. Adams would agree. Roughly speaking, £1,000 a mile would probably cover the cost of railless traction in rural districts. Some of the figures were slightly higher, but he was told that those figures included cables and certain other things which in rural districts were not always necessary.

A point had been made by Mr. Brewer as to the cost of the vehicles. One reason of the high cost up to the present had been that the number manufactured had been very small. There was no reason to suppose that, when the manufacturers began to make vehicles in anything like as large numbers as they now made motor omnibuses, the cost would be any more than the cost of motor omnibuses. They had only got to compare the chassis to know what the relative cost should be.

Mr. E. M. Munro said that during the discussion an earlier speaker had made a comparison between the use of the electric motor and the petrol engine for the purpose of driving road vehicles, very much to the disadvantage of the electro-motor. The electro-motor (series wound) was a machine giving its greatest power at the lowest speed, whereas it was well known that the petrol engine and other internal combustion engines would not start up against any appreciable load. That was a very great advantage in favour of the electro-motor. With regard to weight, at present twenty-eight-seat vehicles, single-deck type, were being built of a weight of $3\frac{1}{2}$ tons. If the Board of Trade were to give their sanction to the use of double-deck buses upon the railless system it would mean a slight additional weight for top seats with increased seating capacity up to forty, at a weight which he thought would compare at least favourably with the present weights of petrol buses.

Control was said to be a little difficult, but they found in Leeds and Bradford that the motormen were trained in about two days to handle the vehicles, and at the official opening of the

system at Leeds the Lord Mayor and Mr. Kitson each took a vehicle and drove it with the greatest ease. They went to the far end of the route, $4\frac{1}{2}$ miles, and returned to the city without stopping.

With regard to tyres, after eight months' running, a very prominent tyre company had undertaken a contract at Leeds at a penny per car mile, which he thought was a very satisfactory figure, considering the condition of the surface of roads and all the circumstances.

Mr. Stephen Sellon said that he had listened to the paper with considerable interest, and he was pleased to find that the author had not put railless traction forward as a cure for everything. He had merely said, "Here is a vehicle that would be exceedingly useful for certain purposes." There he was sure they would all agree that the railless trolley could not take the place of trams. The author said that it would be useful as a feeder to tramway enterprise, and he (Mr. Sellon) thoroughly endorsed that view. A great obstacle to the introduction of railless traction in this country was the fact that when a new system was introduced, promoters were immediately called upon to agree to conditions fatal to reasonable expenditure and economical working. They all knew that when tramways were introduced into a town by a promoter he had by the Standing Orders to get the consent of the local authority before he could introduce his Bill, and this consent had been largely used, and improperly so, for forcing burdensome conditions. When trackless trolley schemes were introduced into this country there was no standing order which required the consent of the local authority, but he found that promoters were eventually giving away the chance of success by agreeing to give a contribution to the road authorities before they started the enterprise, so as to save opposition in Parliament. Could one conceive a more suicidal action than agreeing to contribute towards maintenance of roads when Parliament had already decided that this was an improper demand, as evidenced in the Aberdare case?

He would not argue with Mr. Brewer or anybody else with regard to the cost of tyres. They all knew that it varied from $1\frac{1}{2}$ d. to 2d. per car-mile. That it was a serious item no one denied. He was concerned last Parliamentary session in an undertaking which was proposed for Rotherham, and he found that the first thing that occurred was that the promoters had given an undertaking to the road authorities to pay them so much per car mile to run over their roads, although it was said that the great reason for the promotion was that the outside authorities were clamouring for some means of conveyance.

This, by adding to the cost of tyre repairs, obviously affected the working expenses. The Rotherham line, which was $4\frac{3}{4}$

miles in length, was along a high road in which there was a considerable verge or waste from end to end. It was proposed to introduce a trackless scheme there to serve chiefly a considerable number of miners at various times. A simple calculation would show that the cost of putting down a tramway or a light railway along that waste (which was a familiar thing not only in this country but all over Belgium and elsewhere) would be for $4\frac{3}{4}$ miles about £10,500. This of course is a capital cost over what is required for a railless scheme.

If they calculated the cost of tyres, and the cost of maintenance of the road, which in this case would not be incurred by a tramway, they would find that the cost of tyres and the cost of maintenance together, multiplied by the number of car miles proposed to be run, was more than the interest, depreciation, and maintenance of a track that could be laid down on the waste at the side of a road, and would shew a saving of over £700 a year. He gave that illustration just to show that it was absurd to suggest that the railless traction system was a scheme which was suitable for all kinds of roads and for all kinds of traffic, and could take the place of tramways.

Now, Mr. Brewer had made the extraordinary suggestion that railless traction would take the place of tramways in London. County Council cars holding from 70 to 80 and sometimes 120 passengers went along the Embankment in a continual row. How could those passengers be carried in a trolley car which only had a seating capacity of 25. Yet Mr. Brewer suggested substituting such cars for County Council cars.

Mr. Brewer. That is not what I said.

Mr. Sellon (continuing) said that no one knew better than Mr. Brewer that Parliament had decided that no railless traction car should to-day exceed 5 tons in weight. How, then, was it to carry more passengers? Was Mr. Brewer going to alter legislation? Until he had done so he could not set aside County Council tramways.

Another point was that Mr. Brewer said that tramways were objectionable because they took up such a large space of road. Let them conceive for a moment how many million passengers County Council cars carried and consider what number of railless vehicles would be required to carry them. Which would take up the greater portion of the road and cause the greater obstruction—a County Council tram or an equivalent number of vehicles having a seating capacity of only 25 passengers each, to carry the same number of passengers as the tram?

He did not wish to go into the question of the various systems that the author had referred to, as he was in the position of having to settle at one or two places what particular system should be

adopted; therefore he would not say at the present moment which system he considered best or most suitable.

With regard to the cost of motor buses, he had at various times tried to assist corporations or county councils to install a system of motor buses because they were unable for several reasons to construct tramways. He had never yet in any district outside London, on roads such as had been referred to, known a single case where they had been successful. On the contrary, he had generally found that the working expenses had been more than the receipts.

Mr. B. Deakin said that he had been associated for a number of years with tramways in the colonies, and the question that had been dealt with in the paper was one which appealed to him as of considerable importance. Fortunately in the Australian colonies they were not troubled with the difficulty of getting powers for construction that obtained in this country, and municipalities in the colonies had a greater say in their requirements than here. The routine which had to be gone through for establishing undertakings was very much simpler. The subject was one which he had looked very closely into for a number of years, and in 1893 he had an inspection made of the earliest system in operation in France. While the reports were to some extent favourable, it was thought that further experiments could be made with advantage.

One particular thing which had occurred to him in connection with this subject (which was a new section of the traffic industry, if he might term it so) was the large amount of experimental work that had taken place in connection with various methods, especially the motor bus. Although at the present there were only two practical illustrations of what had been done in railless traction in England, yet they were told that quite uninitiated and inexperienced persons took charge of cars and drove them on their initial trips, and they were further told that the system had worked satisfactorily and exceedingly economically up to the present. That spoke well for those who had undoubtedly given a great amount of time, effort and money to bring the system to its present stage of perfection.

Mr. T. C. Elder said that he would like to congratulate Mr. Adams on the skill and thoroughness with which he had marshalled practically the whole of the facts known concerning all the different systems of trolley omnibuses. He could not find traces of the enthusiasm with which Mr. Boot had credited the author, and the case did not call for enthusiasm so much as for calculated consideration. The paper was a judicial summary of the useful points of railless traction. He looked upon the trolley omnibus as being practically the only method by which

a great many districts could have a system of public transit. He did not think that it was at all necessary to talk about rivalry with tramways or motor buses, but he would like to say to the advocates of motor omnibuses that, when they were prepared to produce a publication of equal bulk with the paper, containing in the same form a faithful record of all the provincial motor omnibus services, then there would be something which could fairly be compared. He challenged them, without any hope of response, to do such a thing. To compare the London General Omnibus Service was simply absurd. That service was picking up passengers by the million all day long and naturally could get the very best technical assistance at headquarters. The great and essential merit of the trolley omnibus system was that it enabled them to have the advantage of taking current from a central station. That system must in all cases be superior to the system of carrying about a generating station on wheels. The whole trend of modern power generation and distribution was to obtain power from a central source, where they had all the advantages of wholesale generation and expert supervision, in preference to generating power for every little factory or every little vehicle. Therefore the great merit of the trackless trolley system was that by several ingenious methods vehicles could now be constructed and run which would have all the advantages of a tramway system in taking power from an overhead wire. He had not heard of any commercial proposition for giving any of our small towns the advantage of motor omnibuses. For such places there was practically no alternative to the trackless system. For that reason he hoped that they would not hear too much about the profit-making possibilities of such schemes. He believed that in many places they would pay expenses and a little over. He thought that it was probably owing to the unfortunate discussion about profits that there were already so many people on the track anxious to tax them, and calling for contributions to road maintenance and other more or less deserving objects. Communities of 20,000 or 30,000 inhabitants could treat themselves to the trackless trolley system, without putting any particular burden on the rates, and for them there was no choice except between that system and pedestrian exercise.

Mr. J. E. Caine said that one speaker had referred to the question of control. In both the Filovia system and the Brush Company's system the control was worked by foot, as in the case of a petrol omnibus.

Mr. H. Conradi said that he preferred tramways to a motor service of any kind as the former seemed to him to be much safer. With regard to speed, he had timed horse and motor

omnibuses in London on half a dozen occasions and found that the motor had never saved more than from 6 to 8 minutes over a distance of $2\frac{1}{2}$ to 3 miles.

Another point was that our roads were not constructed for motor traffic, and to maintain them to support such traffic involved repairs at great cost to the rates, as was not the case with tramways.

He felt certain that the establishment of a line of tramways inclusive of permanent way and rolling stock was not so expensive as the establishment of a motor omnibus service, especially as the tractional resistance of motor buses on the roads was far more than in the case of trams. The tractional resistance on tramway lines was from 25 to 30 lb. per ton in a well organised service. He presumed that the tractional resistance of a motor bus on ordinary roads was from 50 to 60 lb. per ton. The advantage of a motor service lay perhaps in the transport of heavy goods, but that traffic should not be carried on in crowded streets at the busy time of the day.

As regarded working cost, in his experience a tramway service could be carried on at between 6d. and 7d. per car mile, inclusive of maintenance of permanent way and repairs of rolling stock. With electric traction the cost was somewhat higher. Omnibus service, exclusive of repairs and wear of the vehicle itself, and so on, ran to between 8d. and 9d. per car mile. The repairs must be considerable, and the vibration of the machinery was something extraordinary, and naturally so, because, as he had said, the roads were not fit to receive such traffic.

Mr. Norman Scorgie said that he was afraid that none of the speakers had taken the trouble to peruse the very careful volume which had recently been issued by the Traffic Branch of the Board of Trade, which was the second of a series and contained some very interesting figures. The obstruction to the general traffic occasioned by the tramcars was there pointed out, and it was given as the opinion of the advisers of the Traffic Branch of the Board that, if motor cabs were taken as the unit, the motor omnibus would be three, and the tramcar would be ten. Supposing that an omnibus carried twenty-five passengers, as one speaker had said, and a tramcar seventy, he would say unhesitatingly that they would have less obstruction to the general traffic if they had sufficient motor omnibuses on the ratio given for the traffic plying in the streets than they had with fixed cars. He would go further and say that he thought that the officers of the tramway authority would be very well satisfied if each of the cars which ran along the Embankment could be guaranteed to contain twenty-five passengers.

Observations had been made with reference to the cost of obtaining powers by a provisional order as compared with the cost

of obtaining Parliamentary powers. He thought that he speaker who gave the cost as four figures in the case of the Act of Parliament, and less than £200 in the case of a provisional order, must have been giving the figures of an opposed Bill in Parliament on the one hand, and an unopposed provisional order on the other. Perhaps the speaker was hardly aware of the fact that even with a provisional order the promoters had to stand the chance of opposition in the Houses of Parliament, and to deal with the matter over again by having to meet an opposed Bill.

Again, the weight of a twenty-five seated trolley omnibus had been mentioned as 3 tons 12 cwt., and this would carry only twenty-five people. Was it known that the weight of the omnibuses which plied through London at the present time was only 3 tons 10 cwt. for thirty or thirty-four passengers? It had been said by those who were in favour of railless omnibuses that they should make no contribution to the roads, and that they were extremely advantageous to rural districts; but it would be seen from the particulars given on page 36 of the paper that very few of the rural districts were applying for powers. The bodies that were seeking powers were mostly large corporations like Halifax or Rotherham.

Motor omnibuses would ply through two or more districts; but possibly the powers obtained by one of the rural districts might stop at the boundary of the district. Such a thing as that was found in the metropolis at the present time, where passengers had to change at the County boundary from a County Council car to one belonging to an outside Corporation.

All the tramways and the omnibus companies at the present time contributed towards the cost of upkeep of the roads, and, in the volume to which he had referred, there would be found the statement that the contribution of the omnibuses in the metropolis by means of the petrol tax equalled 0.009d. per seat mile, as against 0.008d. by the County Council in respect to the roads which were laid for their lines. Whilst the County Council paid towards the relief of the rates the omnibus companies also paid towards the upkeep of the roads. The major company in the metropolis at the present time was paying £65,000 per annum in respect of the petrol tax; but it was a grievance that London was not getting this money for the upkeep of the roads. The Road Board was keeping it and no part of the receipts from the petrol tax had been spent upon the London roads. He had been told by Sir George Gibb, the Chairman of the Road Board, that the Board had a scheme for a new western road to relieve the traffic at Brentford, and until that was settled upon nothing would be available, as he had to get together the sum of £875,000, which was the Road Board's contribution to the local authorities, and was practically one moiety, if the road authorities paid the

other. Any corporation, as soon as they ran these railless omnibuses upon their highways, would find out what it cost for the upkeep of the roads. He had been very pleased to hear one of the speakers talking about the perfect roads in the metropolis, but he was quite sure that if that gentleman had had anything to do with their maintenance he would not have been so satisfied with their perfection. The complaints received about the nuisance caused by motor omnibuses were gradually increasing, and the damage which they occasioned amounted to a large sum per mile per annum. They could not fix a motor bus company down to traversing a particular route. If they found that the traffic on one route was not sufficient, they would leave it derelict, after it had been made up to suit the 'buses, and the authorities had to make up a second road.

Mr. B. Deakin said that the last speaker had brought out one of the strongest points in favour of the trackless trolley system. He said that the small urban authorities in whose districts the system was required to operate were not applying for Parliamentary powers. Whereas the small authority was not in a position to obtain powers, it could arrange with a larger adjoining municipality to obtain the powers and put a system in operation that could not be established in any other circumstances.

Mr. Brewer said that the arguments which had been raised against his had so little weight in them—and Mr. Scorgie had just knocked the bottom out of one or two of them—that he really thought that it was scarcely necessary for him to say very much. The remark had been made that the development of the motor omnibus had cost a lot of money, but that was no argument at all. If a thing was worth spending a lot of money upon in order to bring it to a satisfactory state, it was evidence in favour of the article. The advocates of the railless system seemed to forget that a lot of money was spent on the development of the traction motor, the benefit of which they got for nothing. In addition, they got the benefit of the motor omnibus chassis for nothing. They started with a vehicle that was a combination of two known quantities. The motor omnibus, when it started, was an entirely new thing, and had to be developed, and those who were benefiting by motor omnibus experience ought to be very satisfied.

One question which Mr. Scorgie had dealt with was tramway obstruction. They must bear in mind that the motor omnibus went at about twice the average speed of a tramcar. Nobody who had ever been through Brentford by tram wanted to do it again. It was a most hopeless performance in congested areas. There the trackless trolley system had enormous advantages

over a tramway with fixed rails. A machine which could be manipulated would carry a very great many more passengers than could possibly be carried by trams or any other system of transit.

REPLY.

Mr. Henry C. Adams then replied. He said that Mr. Harrop's written communication mentioned an important point, namely, the prevention of excessive drop in the return current through the overhead wires. There were many points like that which had to be borne in mind in connection with railless traction, consequently the designing of a scheme was not the simple matter it might appear to the casual observer to be.

As to the question whether the Max-Schiemann and the R.E.T. systems were not the same, the explanation was that, when this method of traction was first tried in this country in 1909, the R.E.T. Company held the sole rights of installing the Max-Schiemann system; but in their opinion it was not suitable for use in this country, and they designed a system of their own, which was very different from the Max-Schiemann system. Descriptions of both were given in the paper.

It was admitted that a lot of money had been spent in developing the motor bus, which had now been brought to a state of considerable efficiency, and the designers of trolley vehicles were, to some extent, profiting by this. The latter system was only in its infancy and could not be compared with the motor bus system; but let the trolley system have ten years more in which to develop towards perfection, and then the two systems might be compared on an equitable basis. In making a comparison, it was of no good to pick out one or two items, such as tyre repairs and cost of vehicles; the whole system should be taken from beginning to end with a view to seeing what return there was on the capital invested.

The weight of the several trolley vehicles was given in the paper, but might be taken as averaging about 3 tons 12 cwt. unloaded; the vehicles were limited by Parliament to five tons when loaded. The maintenance of the tyres on trolley vehicles was being undertaken by leading tyre makers at one penny a car mile. The maximum gradient on the Bradford route was 1 in 15.5, and the flattest 1 in 666.

In any system in which there was a steering-wheel in addition to the controller there might be a disadvantage in the driver having both hands separately occupied, especially if he got into a "tight corner," and possibly that arrangement would be altered in due course. The description of the Brush chassis in the paper referred to a pedal-governed controller applied to the Lloyd-Köhler system, which left the man with

both hands free for steering. In the Filovia system the motors were also controlled in a similar manner by a pedal.

The report of the recent meeting of the County Councils Association, to which reference had been made by Mr. Winter Gray, was a most important matter, because in every scheme which was proposed the County Councils had a very strong voice. They were now making suggestions which would be adopted, probably, by every municipality throughout the country. They not only desired to control everything connected with the vehicles and to make regulations for running them, but also to levy a toll for the use of the road, irrespective of any local circumstances whatever, and even if, by the installation of a trolley vehicle system in substitution for an existing motor omnibus service, the wear on the road was reduced. He had noted some arrangements proposed by local authorities which contained a clause to the effect that those authorities might take possession of railless traction schemes in twenty-one years in a similar way to that in which they took over tramways. He thought that this was trying to strangle a new industry in a very undesirable manner. It was interesting to compare the action of the Italian Government in granting a subsidy to help the development of railless traction in their country, with the action of the County Councils Association and those municipalities in this country who tried by unduly taxing the system to prevent its installation.

The time occupied by two passing vehicles in exchanging their collectors, which was given as 15 seconds, included the time of stopping, changing, and going on again. The exchange would take place, probably, at regular stopping places where the traffic was picked up. But, even if the exchange took place in the middle of the road, it would not be a disadvantage at all in those districts for which this system was suitable.

He presumed he ought to be grateful to Mr. Boot for letting him off so easily after his alleged severe criticism of Mr. Boot's views on a previous occasion ; but he felt that Mr. Boot rather over-estimated the severity of it at the time, and he certainly thought now that Mr. Boot was rather premature in congratulating him upon his conversion. Their difference had never been as regards the system but only as to the application of it. What he (Mr. Adams) had said before, and what he now repeated, was that he did not think that it would be wise to run all over the country linking up small villages. He did consider, however, that the system was eminently suitable for the smaller towns, the outskirts of large towns, and for the less remote rural districts in the vicinity of large towns.

He could not conceive any scheme, even in such rural parts as contemplated by Mr. Boot, which could be constructed without the use of cables. He knew that in some foreign systems

the current was obtained through the overhead wires without cables, but he did not anticipate that that system could be adopted in this country. It had been said that, provided the overhead wires were carried a certain distance back from the boundary of a road and on private property, the Board of Trade would not interfere. But he did not think that they could be carried sufficiently near the edge of the road to be used by the vehicles without at the same time giving the Board of Trade the right to interfere; and, further, inasmuch as the Board of Trade insisted upon the overhead trolley line being broken up into half-mile sections, it was necessary in all schemes to have a feeder cable running along the same route as the trolley wires, whether it was carried under the road, over the road, or alongside the road.

He did not agree with Mr. Boot that the overhead work, including cables, should be constructed for £1,000 per mile. He did not say that it could not be, but he said it ought not to be, especially in those places which he had in his mind. In his paper he had set forth in detail the reasons upon which he based his opinion, and as no endeavour had been made to controvert them he assumed they were generally accepted. The Leeds and Bradford figures for the overhead work which he quoted did not include cables. The overhead work at Bradford averaged £1,684 a mile, which included poles, brackets, trolley wires, guard wires, &c., the allowance for the depot was £100, and two cars, at £700 each, cost £1,400, making a total of £3,605 for the $1\frac{1}{4}$ miles of route. That was equivalent to a capital cost of £2,884 per mile of route, or £1,802 per vehicle. That, he believed, was the original estimate, and there was thus nothing included for cables which, probably, had already been laid in the road to the extent necessary and were therefore available for the purposes of railless traction. The cost which he had given for obtaining powers was the present cost of proceeding by Act of Parliament, and he thought £400 was about the minimum for an unopposed Bill; but the procedure would be cheapened, probably before the end of the year, when it would be possible, if no opposition offered, to obtain the powers for considerably less than £400.

It was remarked by Mr. Conradi that tramways were safer than motor omnibuses. Probably they were; yet motor omnibuses got over the ground more quickly, and a good many things were sacrificed to speed at the present time. As to the relative speeds of horse buses and motor buses, it was, he thought, well known that there was practically no difference in them through the City of London, but, as soon as they got out of the thick traffic, the motor bus ran ahead far away in front of the horse bus.

Mr. Scorgie appeared to confine himself in his remarks

to a consideration of what the trolley vehicle system would be like if it were applied to the busy parts of London, but he (Mr. Adams) considered it to be totally unsuitable, he had not suggested it in his paper, and he had never heard anybody else suggest it seriously, although it had been put forward on occasion by a few people who tried, for some reason or other, to discredit the trackless system by any means. He had not even suggested that the system should run through large provincial towns, and, as he had already stated, he considered it was only suitable for small towns and for the outskirts of the larger towns, as had, in fact, been proposed. Although in many cases the large corporations were taking up the Bills and fathering them, as it were, most of the Bills only proposed to run into the outlying districts of the various authorities, and he did not think that any authority proposed to run the system through the centre of its own town.

He happened to be in Leeds and Bradford a little time ago when the snow was on the ground, and it was exceedingly interesting to notice the way in which the trolley vehicles went through it. In the city, of course, all the roads were perfectly clear and no snow was to be seen, but in the outlying districts it was left lying from six inches to nine inches deep on the road, and the buses had no difficulty whatever in traversing them; but had a tramway system been laid down the cars would, under such conditions, have been held up entirely.

Whether any particular scheme would prove remunerative would depend to a large extent upon the number of car miles per annum which might be run without reducing the receipts per car mile below a predetermined figure. There was only a certain amount of traffic to be carried, and if the service was doubled the receipts per car mile would be halved. If the calculations were based on a running cost of between $4\frac{1}{2}$ d. and 5d., and estimated receipts of 8d., then the service must support at least 80,000 car miles per annum, to be fully remunerative, and, if based on 6d., the service must support at least 200,000 car miles per annum. He thought that it went without saying that those figures could not possibly be obtained in thinly populated rural districts.

1st April, 1912.

JOHN KENNEDY, PRESIDENT,
IN THE CHAIR.

LIGNO-CONCRETE.

By GERALD O. CASE.

[MEMBER.]

SINCE 1907 the author has made a large number of experiments and tests to ascertain if concrete could be efficiently and economically reinforced by timber rods. Concrete has, for many years, been used in conjunction with timber piles for the construction of sea coast and river works ; the concrete serving the purpose of protecting the wood from decay and from the ravages of the *teredo* and other wood-boring insects. In American harbour works the most common method adopted is to place concrete around the previously driven piles, within thin timber tubbing (Fig. 1) or earthenware sewer pipes. When timber tubbing is used it is rapidly eaten away, but the concrete remains to protect the piles. In Australia wharves have been built by driving rows of hardwood piles at suitable intervals and enclosing them in the centre of a concrete wall. This method of construction was used by Mr. T. Parker for the Rockhampton Wharf, and was found to answer well ; the concrete effectively preserved the timber, and the adhesion between the concrete and the timber was very good. When a concrete covering to piles is used in coast works the sea bed is sometimes subsequently scoured out, and it has been found that the concrete filling does not drop to the new sea bed, but adheres to the piles, being supported by the adhesion between the timber and the concrete.

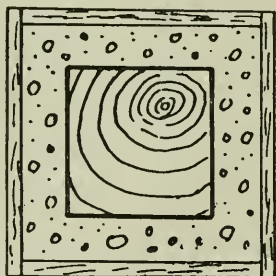


Fig. 1

It appeared to the author that such methods, while being very effective, are costly, as the concrete is used only to preserve the timber ; and it seemed to him that it ought to be possible to combine a framework of timber and concrete in such a way that both materials were utilised to the greatest advantage ; or, in other words, to reinforce concrete by an embedded framework of timber rods.

As is well known, the principle of steel reinforced concrete rests on the fact that while concrete is strong in compression it is

weak in tension ; steel rods, therefore, are placed in the concrete in such a position as to take the tensile stresses ; the concrete taking the compressive stresses.

Roughly speaking, mild steel is about eight or nine times as strong as timber, but ten to fifteen times as expensive. Consequently, if the timber rods can be arranged in such a position in the concrete that their full tensile strength is used, and if there is proper adhesion between the concrete and the timber, there seems to be no reason why timber-reinforced concrete, or ligno-concrete, should not be used successfully as a constructional material.

When a timber rod is embedded in concrete there is a tendency for it to absorb water and increase in size, the amount of enlargement depending on the kind of timber used ; the concrete, on the other hand, contracts when setting in air. It is necessary, therefore, to use the kinds of timber which do not absorb much water, or to treat other timbers in some way so that they do not absorb sufficient water from the concrete to run any danger of splitting the latter. Another point to be considered is the possible subsequent contraction of the timber and reduction of adhesion between it and the concrete. On making a library search the author found that there was an almost entire absence of information on these points, and therefore it became necessary for him to make a large number of experiments and tests.

The timber rods, before the experiments began, were stored under cover together for a month or more, and were carefully weighed before being immersed in water or embedded in concrete blocks, and in the former case the rods were weighted so that they were entirely immersed in the water. When taken out the rods were wiped dry with a cloth before weighing, so that only the water absorbed by the timber was taken into account. When taken out of the concrete the timber rods were carefully cleaned before being weighed. Every care was taken to conduct the various experiments as far as possible under similar conditions.

Water absorbed by various kinds of timber rods immersed in fresh water.—Rods of various kinds of timber, each $7.5 \times 1.2 \times 1.2$ cm., were immersed in fresh water ; the amount of water absorbed by each in one, two, and three days being shown in Table I. It will be noticed that there is a very wide variation in the amount of water absorbed, for while the teak rods absorb only about one-seventh of their dry weight in three days, the poplar rods soak up more than their dry weight in the same time.

It would appear that teak, pitch pine, yellow deal, and jarrah are, in the order given, the best timbers to use for reinforcement. Mahogany and tallowwood absorbed only a small amount of water, but these timbers are expensive and not easily obtainable. These experiments were made with short lengths of rods, whereas

in practice much longer rods would be required, and as the amount of water absorbed per sq. cm. of surface along the grain and across the grain is not equal, it is necessary to ascertain, approximately, the amount of water absorbed in both directions. In practice there will be a large surface along the grain and only a small end surface across the grain; it would therefore be preferable to use for the reinforcement a timber which is not very absorbent along the grain.

TABLE I.

Timber.	Weight, Dry, Grams per cub. cm.	Weight, Dry of Rod, Grams.	Water absorbed in Grams.		
			1 day.	2 days.	3 days.
Poplar	0.443	4.793	3.24	4.91	5.45
Cedar	0.545	5.900	2.58	3.42	4.01
White Deal	0.504	5.543	2.37	2.68	2.98
Odessa Oak	0.809	8.753	2.01	2.58	3.17
Ash	0.775	8.386	1.96	2.50	3.00
Kauri Pine	0.562	6.102	1.70	1.99	2.24
Walnut	0.658	6.980	1.46	1.99	2.45
Stringy Bark	0.670	7.249	1.40	1.90	2.39
English Oak	0.831	8.991	1.40	1.78	2.44
Blue Gum	1.011	10.928	1.30	1.75	2.25
American Oak	0.619	6.698	1.18	1.60	2.01
Jarrah	0.924	9.999	1.15	1.58	1.98
Yellow Deal	0.554	5.994	1.10	1.36	1.65
Pitch Pine	0.739	7.996	0.98	1.34	1.55
Light Mahogany	0.469	5.075	0.92	1.19	1.44
Tallowwood	1.080	11.686	0.80	1.00	1.21
Dark Mahogany	0.831	8.991	0.58	0.85	1.10
Teak	0.674	7.300	0.52	0.79	1.02

Amount of water absorbed per sq. cm. of surface along and across the grain.—Thirteen kinds of timber were selected for experiment, and of each kind one piece $10.3 \times 3.88 \times 3.88$ cm., and two pieces $5.15 \times 3.88 \times 3.88$ were obtained. These pieces were all kept together under cover for about a month before the tests were begun. The cubic content of a single long rod was equal to that of two short rods, *i.e.*, 155.5 cub. cm. The surface area of each of the long rods along the grain was 159.9 sq. cm., and across the grain 30.1 sq. cm. The total surface area of two short rods along the grain was the same as the corresponding area of a single long rod, but across the grain the surface area of two short rods was double that of a long one, *viz.*, 60.2 sq. cm. Therefore, while the two short rods together had the same cubic content as a single long rod and the same surface area along the grain, the cross-grain surface was 30.1 sq. cm. greater. If then the long rod and the two short rods of each kind of timber are taken dry, soaked in water for a short time and then weighed,

the difference in weight will be approximately the amount of water absorbed by 30.1 sq. cm. of end grain in the given short time. If they are again immersed in the water for the same period of time, and then weighed, the difference will not be the true amount of water absorbed by the 30.1 sq. cm. of end grain, for when the rods were immersed the second time the percentage of moisture in the long rod and in the two short rods was not the same. By weighing the two rods at short periods and plotting the results in curves (Fig. 2), showing the amount absorbed in a given period by the two rods with a varying initial percentage of water, it is possible to compare, approximately, for any given period the amount of water absorbed by a long rod, and two short ones having the same initial percentage of water.

Table II. (page 88) gives the results of the experiments which were worked out as explained above.

It will be noticed from Table II. that poplar is the only timber experimented upon which absorbs more moisture per sq. cm. of side than of end surface. American oak absorbs nearly 10 times more water per sq. cm. of end surface than of side surface. Of the other timbers, teak soaks up least water per sq. cm. of side surface, and after three days ceases to absorb any water through the side grain, although absorption continues through the end grain. Poplar, on the other hand, ceases to absorb through the end grain after three days, but continues to do so through the side grain.

It is important to note that the values of X and Y given in the Table II. only hold good for timber which has the same percentage of moisture to dry weight as the pieces which were experimented with. As will be seen later on, the amount of moisture in the timber at the time it is immersed makes a considerable difference to the amount of water absorbed in a given period.

Water absorbed by timber rods having different weights, when immersed in fresh water.—The timber used in previous experiments was well seasoned, and was kept in a dry place for some time before being used. If timber which has been exposed to the weather is used, the weight of the rods per cub. cm. will be greater, due to water absorbed before immersion, and in that case the quantity of water absorbed when the rods are immersed will not be so great.

Table III. shows the weight of water in grams absorbed in one day by various kinds of timber rods, each $10.3 \times 3.88 \times 3.88$ cm. (the several rods of each kind of timber being originally cut from the same plank), which, when immersed in water, had varying weights per cub. cm. owing to some of the pieces being previously more or less impregnated with water. Table III. gives the initial weight and the amount of water absorbed by the rods after immersion in water for one day.

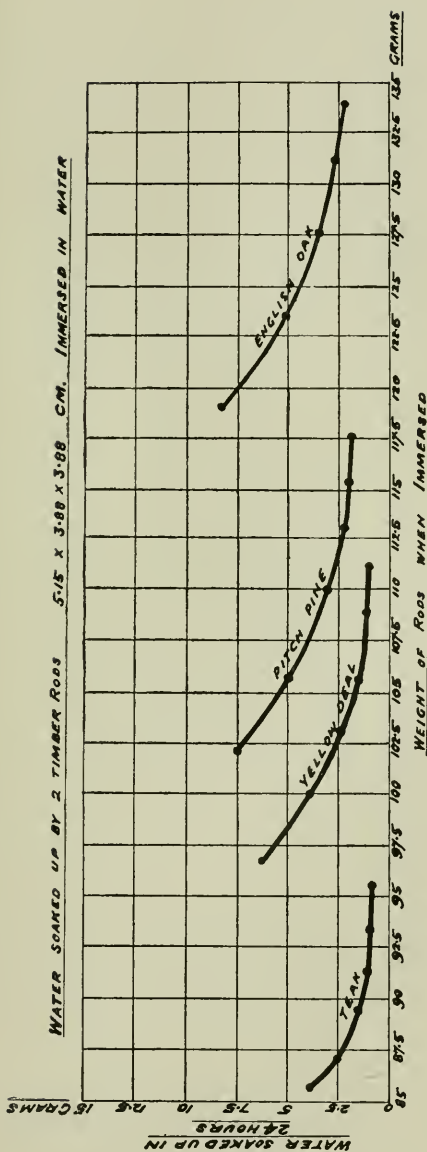


Fig 2

TABLE II.
TIMBER RODS, 3.88 × 3.88 CM. IN CROSS SECTION, IMMERSSED IN FRESH WATER.

Kind of Timber.	Weight of Timber when dry.	X = Amount of Water absorbed per sq. cm. of surface along the grain.					Y = Amount of Water absorbed per sq. cm. of surface across grain.				
		1 day.	2 days.	3 days.	5 days.	7 days.	1 day.	2 days.	3 days.	5 days.	7 days.
Poplar ..	Grams per c.c. 0.4432	Grams. 0.0839	Grams. 0.1145	Grams. 0.1400	Grams. 0.1765	Grams. 0.2136	Grams. 0.0793	Grams. 0.1028	Grams. 0.1586	Grams. 0.1586	Grams. 0.1586
White Deal ..	0.5042	0.0580	0.0592	0.0598	0.0614	0.0712	0.1007	0.1984	0.2953	0.4276	0.5141
American White Wood	0.4210	0.0494	0.0527	0.0564	0.0590	0.0615	0.1019	0.1954	0.2739	0.3931	0.4585
Odessa Oak ..	0.8090	0.0443	0.0573	0.0681	0.0818	0.0937	0.1431	0.2046	0.2550	0.3436	0.4210
Kauri Pine ..	0.5620	0.0416	0.0445	0.0504	0.0550	0.0591	0.0823	0.1382	0.1714	0.2387	0.2932
Ash ..	0.6192	0.0396	0.0446	0.0548	0.0741	0.0822	0.1509	0.2621	0.3549	0.4674	0.5664
English Oak..	0.7622	0.0350	0.0432	0.0486	0.0564	0.0584	0.0942	0.1655	0.2344	0.3374	0.4363
Walnut ..	0.6586	0.0332	0.0441	0.0488	0.0565	0.0611	0.0956	0.1439	0.1816	0.2512	0.3084
American Oak	0.7238	0.0297	0.0346	0.0389	0.0428	0.0617	0.2790	0.4131	0.5096	0.6632	0.7304
Yellow Deal..	0.6494	0.0263	0.0335	0.0371	0.0457	0.0515	0.0799	0.1243	0.1634	0.2160	0.2693
Pitch Pine ..	0.6900	0.0247	0.0376	0.0453	0.0595	0.0767	0.1336	0.1772	0.2171	0.2870	0.3396
Light Mahogany	0.4688	0.0217	0.0296	0.0347	0.0503	0.0592	0.0501	0.0683	0.0967	0.1195	0.1572
Teak ..	0.5814	0.0143	0.0145	0.0155	0.0155	0.0155	0.0616	0.1215	0.1852	0.2458	0.2977

TABLE III.

TIMBER RODS $10.3 \times 3.88 \times 3.88$ CM.

Kind of Timber.	Weight of Rod before immersion in water.	Weight of water absorbed in 1 day.	Remarks.
	Grams. per c.c.	Grams.	
Teak	0.5819	4.00	—
Teak	0.6109	2.80	5% increase in weight=30% decrease in water absorbed.
Teak	0.6400	1.00	10% increase in weight=75% decrease in water absorbed.
Yellow Deal..	0.6494	6.39	—
Yellow Deal..	0.6818	3.20	5% increase in weight=49.9% decrease in water absorbed.
Yellow Deal ..	0.7143	1.75	10% increase in weight=72.1% decrease in water absorbed.
Pitch Pine ..	0.6925	7.70	—
Pitch Pine ..	0.7271	4.50	5% increase in weight=41.5% decrease in water absorbed.
Pitch Pine ..	0.7617	2.50	10% increase in weight=67.5% decrease in water absorbed.
English Oak..	0.7622	8.47	—
English Oak..	0.8003	4.70	5% increase in weight=44.7% decrease in water absorbed.
English Oak..	0.8384	2.75	10% increase in weight=67.2% decrease in water absorbed.

It must be clearly pointed out that the decrease in water absorbed refers only to the increase in weight due to water which had found its way into the timber from outside causes, such as exposure to rain. The same kind of timber, but grown in different soils and climates, varies in weight. The tables do not apply to timbers which, with the same percentage of moisture in each, have a different weight per cub. cm., but only to timbers of the same kind, which, when dried under similar conditions, have the same weight per cub. cm.

Comparison of the amount of water absorbed by timber rods immersed in fresh and sea water.—In order to find out if there was any difference in the amount of water absorbed by timber rods immersed in fresh and sea water, four pieces of pitch pine, each $11.4 \times 3.8 \times 3.8$ cm. were obtained. All four rods were cut from the same piece of timber, which was kept out of doors in the month of August for a few days after arriving from the timber yard. Two of the rods were totally immersed in fresh water from the Brighton Corporation Waterworks, and the other two were totally immersed in sea water obtained from the shore at Rottingdean, Sussex.

TABLE IV.
WATER ABSORBED BY PITCH PINE RODS IMMERSSED IN FRESH AND SEA WATER RESPECTIVELY.

Size of Timber Rod.	Weight of Dry Wood.	Water absorbed in					Water absorbed in 11 days.	Remarks.
		1 day.	3 days.	5 days.	7 days.	9 days.		
	Grams per c.c.	Grams per c.c.	Grams per c.c.	Grams per c.c.	Grams per c.c.	Grams per c.c.	Percent. of dry weight.	
Centimetres.								
11.4 × 3.8 × 3.8	0.668	0.0445	0.0740	0.0937	0.1066	0.1195	0.1323	Immersed in fresh water.
11.4 × 3.8 × 3.8	0.662	0.0447	0.0723	0.0933	0.1058	0.1183	0.1308	"
11.4 × 3.8 × 3.8	0.652	0.0455	0.0755	0.0974	0.1106	0.1238	0.1370	Immersed in sea water.
11.4 × 3.8 × 3.8	0.676	0.0457	0.0785	0.1016	0.1148	0.1279	0.1411	"

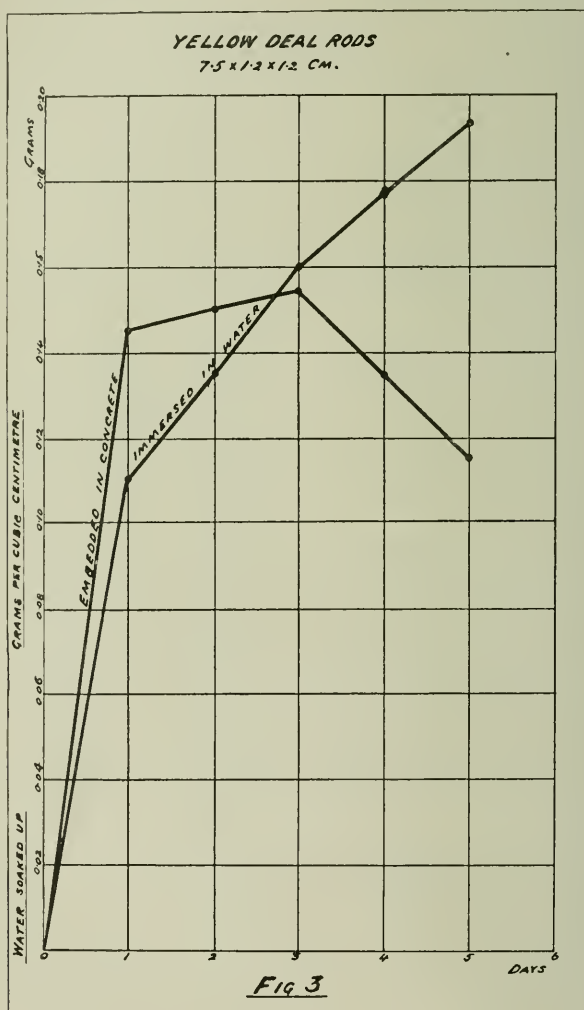
TABLE V.

WATER ABSORBED IN GRAMS PER CUBIC CENTIMETRE BY TIMBER RODS IMMersed IN FRESH WATER AND EMBEDDED IN CONCRETE BLOCKS.

Kind of Timber.	Size of Rods.	Weight.	Water absorbed in						Water absorbed in 4 days.	Water absorbed in 2 days.	Remarks.
			1 day.	2 days.	3 days.	4 days.	5 days.	6 days.	7 days.		
			Grams per c.c. (Aver. of 5 rods)	Grams per c.c. (Aver. of 5 rods)	Grams per c.c. (Aver. of 5 rods)	Grams per c.c. (Aver. of 5 rods)	Grams per c.c. (Aver. of 5 rods)	Grams per c.c. (Aver. of 5 rods)	Grams per c.c. (Aver. of 5 rods)	Per centage of dry weight.	Per centage of dry weight.
Teak ..	Centimetres, $7.5 \times 1.2 \times 1.2$	Gram 0.6300 (Aver. of 5 rods)	0.0619	0.0967	0.1158	0.1270	0.1390	—	—	—	Immersed in fresh water. Embedded in concrete blocks $12.7 \times 10.1 \times 10.1$ cm.
Teak ..	$7.5 \times 1.2 \times 1.2$	Gram 0.6300 (Aver. of 5 rods)	0.0660	0.1285	0.1430	0.1266	0.0522	—	—	—	Immersed in fresh water. Embedded in concrete blocks $12.7 \times 10.1 \times 10.1$ cm.
Deal ..	$7.5 \times 1.2 \times 1.2$	Gram 0.5400 (Aver. of 5 rods)	0.1110	0.1352	0.1604	0.1769	0.1933	—	—	23.00	Immersed in fresh water. Embedded in concrete blocks $12.7 \times 10.1 \times 10.1$ cm.
Deal ..	$7.5 \times 1.2 \times 1.2$	Gram 0.5400 (Aver. of 5 rods)	0.1450	0.1497	0.1543	0.1352	0.1160	—	—	26.66	Immersed in fresh water. Embedded in concrete blocks $12.7 \times 10.1 \times 10.1$ cm.
Teak ..	$11.4 \times 1.9 \times 1.9$	Gram 0.5814 (Aver. of 8 rods)	0.0433	0.0518	0.0651	0.0706	0.0760	0.0805	0.0849	14.57	Immersed in fresh water. Embedded in concrete blocks $15.2 \times 6.2 \times 6.2$ cm.
Teak ..	$11.4 \times 1.9 \times 1.9$	Gram 0.6080 (Aver. of 8 rods)	0.0461	0.0777	0.1057	0.1346	0.1215	0.0891	0.0833	19.61	Immersed in fresh water. Embedded in concrete blocks $15.2 \times 6.2 \times 6.2$ cm.

Table IV. (page 90) shows the results of weighing all four rods at various periods. Making allowance for the fact that the percentage of moisture in the four rods varied slightly, it appears that timber rods immersed in salt water absorb rather more than when immersed in fresh water.

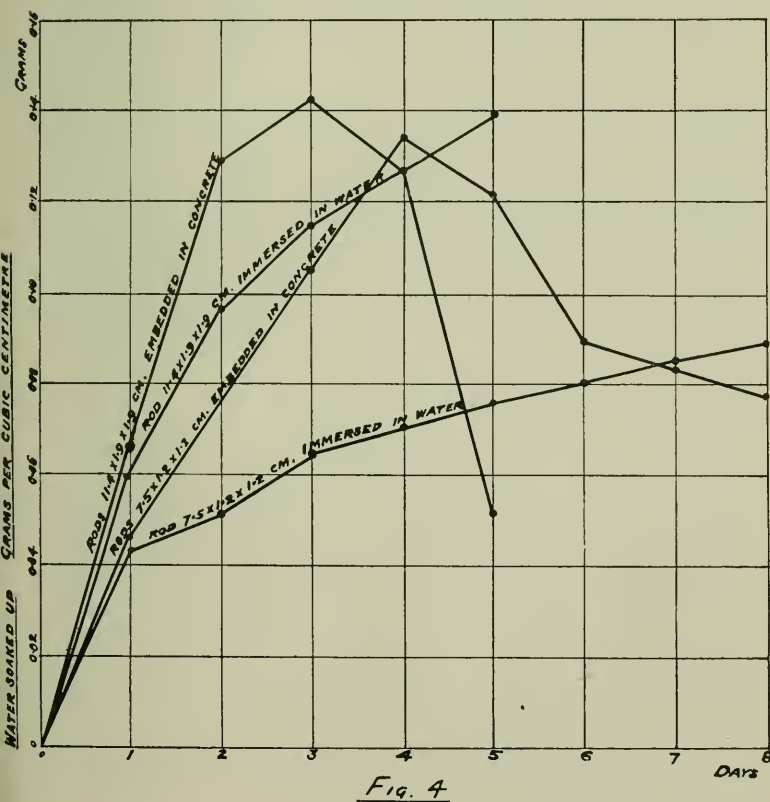
Comparison of the amount of water absorbed by timber rods immersed in fresh water and embedded in concrete blocks.—To find out how the amount absorbed by rods totally immersed in fresh water compared with the amount absorbed by similar



rods embedded in concrete, a number of experiments were made. Teak and yellow deal rods, $7.5 \times 1.2 \times 1.2$ cm., were used, and the size of the concrete blocks, in the centre of which these rods were embedded, was $12.7 \times 10.1 \times 10.1$ cm. Teak rods, $11.4 \times 1.9 \times 1.9$ cm., were also experimented with, and for this size of rod the concrete blocks were made $15.2 \times 6.2 \times 6.2$ cm. The concrete used was in most cases obtained from gaugings which were being made on the Sea Defence Works at Rottingdean. The strength of the concrete was, approximately, 6 parts seashore ballast and 1 part cement; no special amount of water was used in gauging, but the concrete was generally fairly wet. Care was taken to see that the amount of sand was sufficient to fill the voids in the shingle pebbles.

Table V. (page 91) and the curves (Figs. 3 and 4) show the results obtained. From the experiments made it seems clear that a

TEAK RODS



timber rod embedded in a concrete block will absorb more water during the first day or two than a similar timber rod immersed in fresh water. Referring to the curves, it will be seen that the weight of the rods immersed in water increases steadily owing to the water absorbed.

The rods embedded in concrete increase rapidly in weight while the concrete is setting, and then decrease in weight owing to water evaporated. It will be noticed that the largest size teak rods embedded in concrete increased in weight for four days, and then began to decrease, while the smaller teak rods increased in weight for three days only, and then began to lose weight. The small yellow deal rod continued to absorb water for three days. At one and two days the amount absorbed was in excess of the amount of absorption by similar rods immersed in fresh water, but at three days it was less.

Comparison of the amount of water absorbed by timber rods immersed in fresh water and embedded in blocks of concrete and neat cement.—The experiments were made with various kinds of timber rods, each $7.5 \times 1.2 \times 1.2$ cm. Table VI. shows the results.

The number of experiments made was not sufficient to establish any definite ratio between the amount of water absorbed by dry timber rods immersed in water and embedded in 6 to 1 concrete blocks and neat cement blocks. It appears that the rods embedded in neat cement blocks absorb in one day from 1.1 to 2.19 times as much water as similar rods totally immersed in fresh water; the average for the five kinds of timber tried being 1.44. The rods embedded in the 6 to 1 concrete blocks absorbed in one day from 1.33 to 1.66 times the amount of water absorbed by similar rods when totally immersed in fresh water, the average for the three kinds of timbers experimented upon being 1.53.

Tendency of dry timber rods to split the concrete blocks in which they are embedded.—All the concrete and neat cement blocks in which the dry timber rods were embedded (referred to in Tables V. and VI.) became cracked within a period of one to three days, with the exception of the concrete blocks containing teak rods. As soon as the block has cracked, it is probable that the rod begins to dry out fairly rapidly, and therefore the amount of water given as that absorbed from the concrete is probably on the low side, except for the teak rods. A dry teak rod (weight 0.603 gram per cub. cm.) of 1.44 sq. cm. sectional area, will not crack a concrete block (6 to 1 concrete) of 26 sq. cm. sectional area, in the centre of which it is embedded. Other experiments made showed that a teak rod (weight 0.677 gram per cub. cm.) of 3.61 sq. cm. sectional area, will not crack a concrete block (6 to 1 concrete) of 29.16 sq. cm. sectional area, in the centre of which it is embedded.

TABLE VI.

Kind of Timber.	Weight, Dry.	Weight, Dry.	Quantity of Water absorbed in 24 hours.			Remarks.
			Immersed in Fresh Water.	Embedded in 6 to 1 Concrete Block.*	Embedded in Neat Cement Block $5.1 \times 5.1 \times 10.2$	
		Grams.	Grams.	Grams.	Grams.	
English Oak ..	8.85	per c.c. 0.81	1.39	—	1.82	$1.82 = 1.39 \times 1.309$
Tallowwood ..	11.66	1.07	0.78	—	0.85	$0.85 = 0.78 \times 1.089$
Ash ..	8.50	0.78	1.98	—	2.62	$2.62 = 1.98 \times 1.323$
Jarrah ..	9.96	0.91	1.17	—	1.52	$1.52 = 1.17 \times 1.30$
Yellow Deal ..	6.05	0.55	1.09	1.50	—	$1.50 = 1.09 \times 1.376$
Mahogany.. ..	9.15	0.84	0.48	0.80	—	$0.80 = 0.48 \times 1.660$
Teak ..	7.03	0.65	0.57	—	—	—
Teak ..	6.49	0.60	—	0.90	—	$0.90 = 0.57 \times 1.57$
Teak ..	7.57	0.70	—	—	1.25	$1.25 = 0.57 \times 2.19$

* Beach and sand 6 parts, cement 1 part.

The dry teak rod (weight 0.70 gram per cub. cm.) $7.5 \times 1.2 \times 1.2$ cm., which was embedded in the centre of a neat cement block, $10.2 \times 5.1 \times 5.1$ cm., cracked the block when about 1 day old. The block was then broken up and the rod weighed, the increase in weight being 1.25 grams. It appears, therefore, that a dry teak rod (weight 0.70 gram per cub. cm.) of 1.44 sq. cm. sectional area, will crack a neat cement block of 26 sq. cm. sectional area in the centre of which it is embedded.

A number of experiments were also made with dry pitch pine rods embedded in concrete blocks. It was found that a dry pitch pine rod, $7.5 \times 1.2 \times 1.2$ cm., weighing 0.733 gram per cub. cm., split a 6 to 1 concrete block $10.2 \times 5.1 \times 5.1$ cm. in the centre of which it was embedded.

The same size pitch pine rods, and cut from the same plank, were then embedded in blocks $10.2 \times 7.55 \times 7.55$ cm. and $10.2 \times 10.2 \times 10.2$ cm. respectively. In both cases the dry pitch pine rods split the concrete. Another dry rod of the same size, and cut from the same plank, was then immersed in water for two days, and weighed, and was found to have taken up 1.47 grams of water, when its weight was 0.869 gram per cub. cm. It was then embedded in the centre of a 6 to 1 concrete block $10.2 \times 5.1 \times 5.1$ cm. After three days a very slight crack was seen in the block. Another dry rod, of the same size and from the same plank, was soaked in water until its weight was 0.9 gram per cub. cm. It was then embedded in the same size block as before, and no cracks were found up to 28 days after it was made, when the block was broken up.

A dry pitch pine rod, $10.2 \times 1 \times 1$ cm., weighing 0.733 gram per cub. cm., was soaked in water until its weight was 0.85 gram per cub. cm., and was then embedded in the centre of a 6 to 1 concrete block $10.2 \times 5.1 \times 5.1$ cm. No cracks were observed up to 15 days, when the block was broken up, the rod cleaned and weighed, and found to be 0.79 gram per cub. cm.

Table VII. shows that if a pitch pine rod is dry it will split a concrete block, even if the area of the rod in cross section is only $\frac{1}{12}$ of the area of the concrete block. It was found that if the rod is soaked for only a short time, it very greatly reduces the expansion, and that the blocks do not split when rods (initial weight 0.733 gram per cub. cm.) are soaked until the weight is about 0.9 gram per cub. cm.

In order to find the effect of using porous as compared with solid concrete, six mahogany rods, each $7.5 \times 1.2 \times 1.2$ cm., were cut from the same plank, the weight of the rods being 0.898 gram per cub. cm. Three blocks were made with concrete composed of sand and fine ballast 6 parts and cement 1 part, care being taken that there was sufficient sand, so that the concrete would not be porous. The other three blocks were made with the same strength of concrete, but did not contain enough sand to

TABLE VII.

PITCH PINE RODS EMBEDDED IN CENTRE OF 6 TO 1 CONCRETE BLOCKS
(ALL RODS CUT FROM SAME PLANK).

Cross-sectional Area of Rod.	Weight of Rod.	Gross Cross-sectional Area of Concrete Block (i.e., including area of Rod).	Remarks.
Sq. cm. 1.44	Grams per c.c. 0.733	Sq. cm. 26	Block split.
1.44	0.733	56	Block split.
1.44	0.733	104	Block split.
1.44	0.869 (after soaking in water)	26	Very slight crack one side.
1.44	0.900 (after soaking in water)	26	No cracks, block kept for 28 days.
1.00	0.85 (after soaking in water)	26	No cracks, block kept for 15 days, weight of rods then 0.79 gram per cub. cm.

TABLE VIII.

MAHOGANY RODS $7.5 \times 1.2 \times 1.2$ CM.; WEIGHT OF DRY RODS, 0.861 GRAM PER CUB. CM.; CROSS-SECTIONAL AREA OF ROD, 1.44 SQ. CM.; GROSS CROSS-SECTIONAL AREA OF BLOCK IN CENTRE OF WHICH ROD WAS EMBEDDED, 26 SQ. CM.

Time Rod was in Block.	Weight of Rod per cub. cm. when taken out of Block.	Weight of Water absorbed.	Remarks.
Days. 2	Grams. 0.925	Grams. 0.70	Porous block.
2	0.992	1.42	Solid block.
4	0.937	0.82	Porous block.
4	1.000	1.50	Solid block, slight crack on one side.
6	0.861	—	Porous block.
6	0.898	0.40	Solid block, slight crack on one side.

fill entirely the voids between the pebbles. When the blocks were two, four, and six days old respectively, one porous block and one solid block were broken and the rods weighed. When four days old, cracks appeared in the solid blocks, but no cracks were seen in the porous blocks. The amount of water absorbed by the mahogany rods in both kinds of blocks is shown in Table VIII. (page 97). It will be seen, therefore, that if the concrete is at all porous, the rod does not absorb so much water from the concrete, and it also more quickly loses what it has absorbed.

Experiments to ascertain the amount of water absorbed by treated (painted, creosoted, &c.) timber rods embedded in concrete blocks.—A number of various kinds of timber rods were obtained, stored together under cover for four weeks, and then cut into a number of rods, all $7.5 \times 1.2 \times 1.2$ cm. Three of these rods, American oak, jarrah, and teak, were painted with two coats (paint made with white lead, linseed oil, turps, and brown umber), and when thoroughly dry, embedded in the centre of concrete blocks $10.2 \times 5.1 \times 5.1$ cm. made of concrete composed of sand and beach 6 parts, cement 1 part. At the same time dry, untreated timber rods of the same kinds were also embedded in the centre of similar concrete blocks. The results of these experiments are given in Table IX.

From the results obtained it will be seen that painting the rods does not prevent their absorbing water when embedded in concrete blocks, although it diminishes the amount absorbed. Four of the rods (American oak, jarrah, blue gum, and teak) were treated with "Wood Preservative" kindly supplied by N. C. Szerelmey & Co., and when thoroughly dry were embedded in concrete blocks of the same size and composition as before. The comparative amount of water absorbed by such treated rods and by untreated rods is shown in Table X.

A yellow deal rod and a teak rod had two coats of varnish, and were then embedded in concrete blocks as before. The varnished teak rod absorbed 0.86 gram of water in three days as compared with 1.48 gram for an untreated rod for the same period. The varnished yellow deal rod absorbed 0.46 gram of water in three days, as compared with 1.6 gram for an untreated rod for the same period. The experiments are summarised in Table XI. (page 100). All the blocks cracked excepting those with the teak rods in them, and as the rods lose water more rapidly as soon as the blocks crack, the results are only useful to give a comparison of the effectiveness of painting, &c.

It seemed possible to the author that properly creosoted oak or deal rods would not absorb water from concrete blocks in which they were embedded. Several yellow deal and oak rods about $45.6 \times 3.76 \times 3.76$ cm. were obtained. After creosoting, the weight of the oak rod was 0.876 gram per cub. cm., and the yellow deal rod 0.690 gram per cub. cm. Four of the creosoted

TABLE IX.

Timber.	Weight, Dry.	Weight, Dry per cub. cm.	Weight after painting.	Paint used per sq. cm. of surface of Rod.	Time timber was in Block.	Amount of Water absorbed.	Remarks.
American Oak	Grams. 6.31	Grams. 0.583	Grams. 6.97	Grams. 0.017	Days. 3	Grams. 0.98	Block cracked.
Jarrah	9.29	0.858	9.88	0.015	3	1.01	"
Jarrah	9.29	0.858	—	—	3	1.82	"
Teak	7.52	0.695	8.28	0.019	3	0.573	Block not cracked.
Teak	7.52	0.695	—	—	3	1.480	"

TABLE X.

Timber.	Weight, Dry.	Weight, Dry per cub. cm.	Weight after Treating.	Preservative used per sq. cm. of Rod Surface.	Time timber was in Block.	Amount of Water absorbed	Remarks.
American Oak	Grams. 6.31	Grams. 0.583	Grams. 6.56	Grams. 0.006	Days. 3	Grams. 1.49	Block cracked.
Jarrah	9.29	0.858	9.42	0.003	3	1.50	"
Jarrah	9.29	0.858	—	—	3	1.82	"
Teak	7.52	0.695	7.70	0.004	3	1.01	Block not cracked.
Teak	7.52	0.695	—	—	3	1.48	"
Blue Gum	10.84	1.001	10.89	0.001	3	1.81	Block cracked.
Blue Gum	10.84	1.001	—	—	3	2.40	"

TABLE XI.

TIMBER RODS $7.5 \times 1.2 \times 1.2$ CM. EMBEDDED IN 6 TO 1 CONCRETE BLOCKS
 $10.2 \times 5.1 \times 5.1$ CM. FOR THREE DAYS.

Timber.	Water absorbed in 3 days.	Remarks.
American Oak, painted ..	Grams. 0.98	All blocks found cracked when three days old.
American Oak, treated with "Wood Preservative" ..	1.49	
Jarrah, not treated	1.82	
Jarrah, painted	1.01	
Jarrah, treated with "Wood Preservative"	1.50	
Blue Gum, not treated ..	2.40	
Blue Gum, treated with "Wood Preservative"	1.81	
Yellow Deal, not treated ..	1.60	
Yellow Deal, varnished ..	0.46	
Teak, not treated	1.480	None of blocks cracked.
Teak, painted	0.573	
Teak, treated with "Wood Preservative"	1.010	
Teak, varnished	0.860	

oak and yellow deal rods were embedded in concrete blocks 27.8×27.8 cm. in cross section, the rods being placed in the corners of the blocks 2.6 cm. from the outside. In both cases the rods split the blocks. Other experiments, however, showed that creosoting diminished the amount of water absorbed from the concrete, and previous soaking of the creosoted rods for a short time prevented them from splitting the concrete blocks.

A considerable number of other blocks of various sizes were made, and painted or creosoted timber rods embedded therein. In every case, except where teak or mahogany rods were used, the blocks cracked. When mahogany rods were used, some of the blocks cracked and some did not.

As none of the blocks in which the teak rods was embedded cracked, we can, for this timber, compare the relative amounts of water absorbed by treated and untreated rods $7.5 \times 1.2 \times 1.2$ cm.

embedded in concrete (beach and sand 6 parts, cement 1 part and immersed in fresh water.

If W = Weight in grams of water absorbed by a dry teak rod immersed in fresh water for three days ;

then

1.34 W = Weight of water absorbed by the rod embedded in a 6 to 1 concrete block for three days.

0.52 W = Weight of water absorbed by rod painted with two coats and embedded in a 6 to 1 concrete block for three days.

0.78 W = Weight of water absorbed by rod, varnished, and embedded in a 6 to 1 concrete block for three days.

From the tests made the author concluded that the easiest way to prevent the concrete blocks being split was to soak the rods (except the teak rods) in water before embedding them in the concrete.

Effect of soaking timber rods on the adhesion between timber and concrete.—Several ligno-concrete posts were made with oak and yellow deal reinforcements, which were soaked for three days before being embedded in the concrete. When broken up at three months old it was found that the adhesion between the concrete and the timber was very good ; small pieces of timber being torn away from the rods and firmly adhering to the concrete in breaking up the posts.

In May, 1910, a concrete block of 30.4×30.4 cm. cross section and 20.3 cm. deep was made, having embedded in it four creosoted deal rods 2.5×2.5 cm. in cross section and 10.1 cm. long, which had previously been soaked in water for two days ; the rods being placed in the four corners 5 cm. from the outsides of the block. In August, 1911, when fifteen months old, the block was broken up. The concrete on the top and bottom of the rods was first knocked off, exposing the four rods, which were then hit with a hammer to drive them through the concrete. It was found that considerable force was necessary to move them. When the rods were driven out through the concrete it was found that the sides of the rods in places were torn, and the corresponding pieces of wood were still adhering to the sides of the holes in the block where the rods had been.

Timber rods adhere to concrete partly by superficial absorption, and partly through the pressure resulting when the concrete sets and contracts. When dry and rough wood is used, some of the cement concrete enters through the fibres, and, getting a hold, covers the wood with a solid layer which is difficult to detach. It is obvious that if the timber is soaked previous to its being embedded in the concrete it must subsequently contract slightly ; and it appears that the contraction of the concrete is sufficient to counteract this. The co-efficient of contraction of concrete

setting in air is given by Considère as 0·0005. The various kinds of timber rods experimented with had only to be soaked for a few days to prevent them cracking the concrete, and in this time they were not anything like impregnated through with moisture. Experiments made with yellow deal, oak, and ash rods $11\cdot4 \times 3\cdot8 \times 3\cdot8$ cm. showed that if kept immersed in water they continue to absorb it for a long time. The yellow deal rod ceased to absorb water after 30 days, but the other rods were still taking up water after 200 days' immersion, the amount of water absorbed being:—Yellow deal, in 30 days, 40·8 grams; oak, in 200 days, 69·2 grams; ash, in 200 days, 83·20 grams. It is of equal importance therefore in the case of ligno-concrete, as in steel reinforced concrete, to avoid using porous concrete.

A concrete post was made with oak reinforcements which were soaked before being embedded in the concrete. This post was then placed in a pool on the foreshore below mean sea level, and after being exposed to tidal action for six months, was examined, and no cracks could be seen. In making this post special care was taken to ensure that the concrete was not porous.

Conclusions from preliminary tests.—From the preliminary tests made the author concluded that the difficulty of the expansion of timber rods when embedded in concrete could be avoided by using teak, and could be overcome in the case of other timbers by soaking them in water before embedding them in the concrete; and, further, that such soaking did not seriously affect the adhesion between the timber and the concrete.

Preservation of timber inside concrete.—There are many examples of a concrete covering to timber being found very efficient in preserving the timber from decay, and preventing it being destroyed by marine insects. When the old convict prison at Chatham was pulled down, a number of yellow deal levelling stumps, about 2in. square, were found embedded in the concrete foundations. The parts of the stumps which were embedded in the concrete were found to be in a perfect state of preservation, but those which had projected into the ground below had completely rotted away. In 1911 the author removed from the site of Volk's Railway, on the foreshore between Rottingdean and Brighton, a number of concrete blocks in which were embedded oak posts 4×4 in. square, part of the posts projecting above the concrete. These posts had been in position on the shore over ten years. The parts of the posts projecting above the concrete were found to be both eaten and rotted away. On the average 20% of the original volume of oak was destroyed. After breaking up the blocks the parts of the posts which were embedded in the concrete were, as far as could be seen, in a perfect state of preservation.

If the concrete is properly made, and the timber is not exposed to air or moisture, it does not appear possible for it to

decay ; but in the case of soft timbers they can, as a precaution, be creosoted before being embedded in the concrete.

*Tests on ligno-concrete beams.**—On July 29th and September 10th, 1910, tests were made of a number of ligno-concrete and plain concrete beams at the Brighton Municipal Technical College, before several engineers and others, including Dr. Burnie, Prof. C. A. M. Smith, M.Sc., and the author. The tests were made on beams $4\frac{1}{2} \times 4\frac{1}{2} \times 55$ in. long. The beams were made on the cliffs at Rottingdean in timber moulds, four being made at a time from the same gauging of concrete, which was composed of 1 part granite chips, $\frac{1}{2}$ part fine sand and $\frac{1}{2}$ part coarse sea sand, and $\frac{1}{3}$ part cement (B.E.S.C. specification) for the beams Nos. 3, 4, 5, 6, 7, and 9. For the beams Nos. 1, 2, and 8 fine beach was used instead of granite chips. The reinforcing rods in beams Nos. 3, 4, and 5 had a number of nails driven into the wood and projecting $\frac{1}{4}$ in. The reinforcing frames, with the exception of the one made with teak rods, were soaked in water for two or three days before putting them into the concrete. The beams were all loaded in the centre, the span being 42 in. The results of the tests are summarised in Table XII. (page 104). A framework only of stringy bark rods (Fig. 5) was also tested ; the breaking load of the rods on the compression side was 300 lb.

REINFORCEMENT

BEAMS NOS 1 AND 3-9



FIG 5

REINFORCEMENT

BEAM No 2

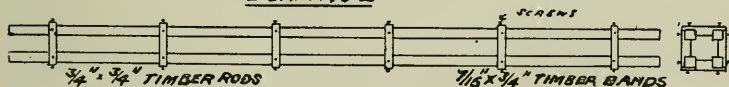
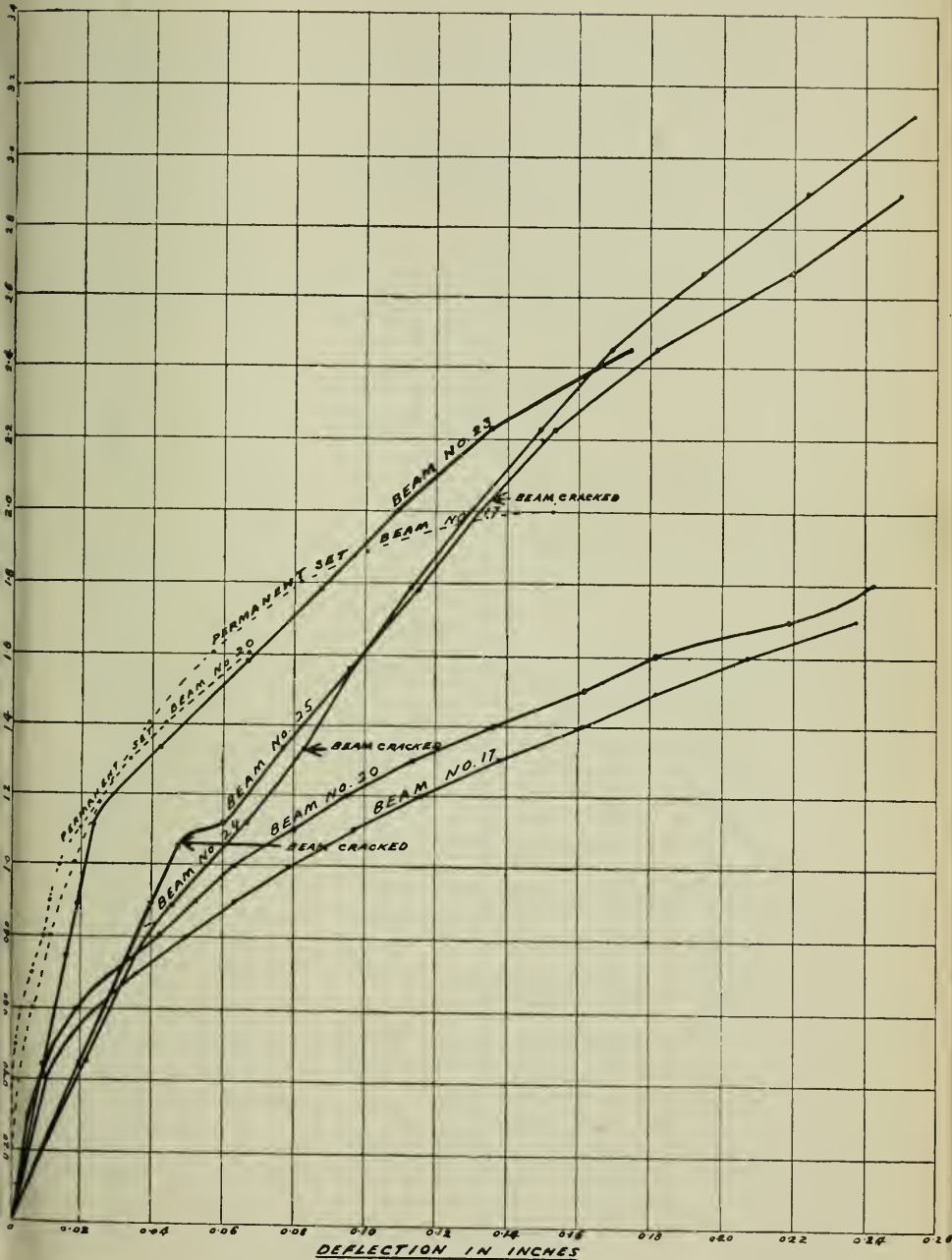


FIG 6

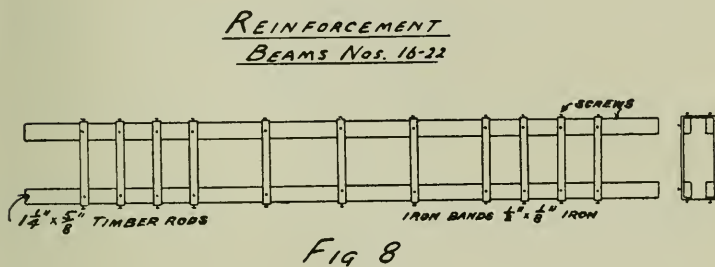
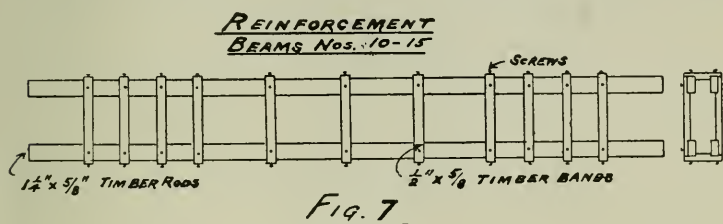
* In the experiments on timber rods immersed in fresh water or embedded in concrete the metric system was used by the author for all calculations, and he has not worked out the results in the equivalents of the imperial system, as he thinks that for convenience and simplicity any further experiments will be worked out in metric units. For the tests on beams the author has used the lb.-foot and ton-foot units, as by doing so the tests on ligno-concrete can be more easily compared with tests on ferro-concrete beams.

TABLE XII.

Beam No.	Description of Reinforcement.	Age of Beam.	Load producing first crack.	Maximum Load.	Remarks.
1	$\frac{3}{4}$ in. Jarrah Rods (Fig. 5)	Days. 10	lb. 850	lb. 3,300	Crack gradually opened. Rods broke at maximum load.
2	$\frac{3}{4}$ in. Tallowwood Rods (Fig. 6)	10	1,050	3,150	Four cracks gradually opened. Rods broke at maximum load.
3	$\frac{3}{4}$ in. Teak Rods	12	1,400	2,500	Three cracks gradually opened. Rods broke at maximum load.
4	$\frac{3}{4}$ in. Yellow Deal Rods	6	Cracked in cartage 1,400	2,250	Crack gradually opened. Rods broke at maximum load.
5	$\frac{3}{4}$ in. Oak Rods	14	(Fig. 5)	2,240	
6	$\frac{3}{4}$ in. Ash Rods	12	1,000	1,800	
7	$\frac{3}{4}$ in. Mahogany Rods	12	1,200	1,595	
8	Granite Concrete not reinforced	10	—	650	
9	Beach Concrete not reinforced	14	—	425	

FIG. 9

Twelve ligno-concrete beams, 8in. deep by 4in. wide and 4ft. 6in. long, reinforced with oak and yellow deal rods (Figs. 7 and 8), and one plain concrete beam, were tested for the author by Prof. C. A. M. Smith, M.Sc., at East London College (London Univer-



sity). The beams were made with concrete of the proportions used for the small beams. All the reinforcing frames were soaked in water before putting them in the concrete.

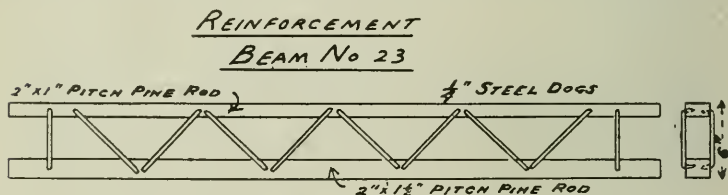
The beams were loaded in the centre, the span being 4ft., and as $M = \frac{wl}{4}$, and $l = 4\text{ft.}$, therefore M in [ton ft. is numerically equal to the applied load in tons, *i.e.*, a load of 1 ton produces a bending moment of 1 ton-foot. Readings were taken on the deflection of the beam for each load, the load being then removed, and the amount of permanent set noted. The results for beams Nos. 17 and 20 are plotted in curves (Fig. 9). The results of the tests are summarised in Table XIII. (p. 106). For beam No. 22 the maximum load was 0.25 ton, and the maximum deflection was 0.003in.

The tensile stress in the concrete was 157 lb. per sq. in., and the modulus of elasticity of the concrete 2.1×10^6 lb. per sq. in. After fracture the beams were broken up and the condition of the reinforcement examined. In practically every case there were signs that the reinforcement had slipped through the concrete. While the results of the tests on the ligno-concrete beams made at East London College (Figs. 7 and 8) are interesting, they are not of much practical value, as the method of reinforcement is not a very good one.

TABLE XIII.

Beam No.	Reinforcement.		Age.	Ultimate Load at Centre of Beam.	Load at Yield Point.	Deflection at Yield Point.
	Main.	Shear.				
10	Deal	Deal	Days. 116	Tons. 1.2	Ton. 0.60	In. 0.010
11			120	2.0	0.70	0.015
12			107	1.95	0.63	0.017
13	Oak	Oak	102	1.0	0.42	0.005
14			102	1.15	0.40	0.013
15			62	1.4	0.40	0.024
16	Oak	Iron	104	2.67	0.90	0.014
17			102	2.00	0.45	0.010
18			107	1.80	0.76	0.011
19	Deal	Iron	66	2.58	0.40	0.009
20			68	2.28	0.50	0.010
21			68	1.70	0.50	0.013
22	Plain	Concrete	99	0.25	—	—

On September 29th, 1911, three ligno-concrete beams were tested at the Brighton Technical College in the presence of Dr. Burnie, the author, and others. The beams were all made on the 24th August, 1911, with concrete composed of cement, sand, and beach in proportion of $1 : 1\frac{1}{2} : 3$. The cement used was "chamber" cement (B.E.S.C. specification). The beams were reinforced by a timber framework formed of pitch pine rods and diagonal metal or timber bracing (Figs. 10, 11, and 12). All three reinforcing frames were soaked in water before they were

FIG 10

REINFORCEMENT
BEAM No. 24

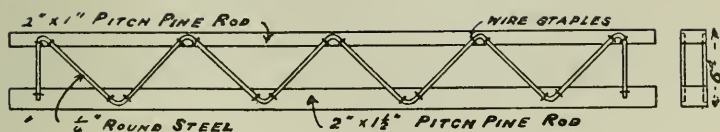


FIG 11

REINFORCEMENT
BEAM No. 25

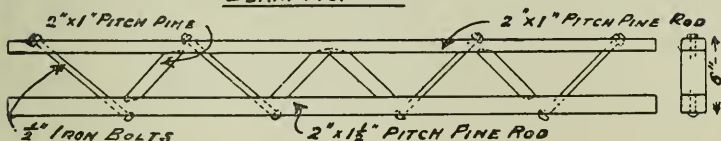


FIG 12

put in the concrete. The size of the beams was 8 in. deep, 4 in. wide, and 4 ft. 6 in. long; the reinforcing frame being embedded in the centre of the beam. The beams were tested with a central load on a 4 ft. span, and the applied load read off in tons as $M = \frac{wl}{4}$ and l being 4 ft., M in ton-ft. = the applied load in tons

(numerically). Readings were taken on the deflection of the beams at various loads, and the results are plotted on curves (Fig. 9). On reference to these it will be seen that the deflection increases uniformly at first, and then, at a more or less definite point, increases rapidly, just as does that of a steel tension specimen at its yield point. The load at which the first crack was visible is marked on the curves. In the case of No. 25 beam a large crack suddenly appeared, and a report like that of a pistol was heard. The results of the tests are summarised in Table XIV.

After the load was removed the beams were carefully broken up with a hammer. In all three cases there were indications that the reinforcement had slipped through the concrete.

Prof. C. A. M. Smith has suggested notching the tension bars to afford a positive grip to the concrete. The notches could be arranged so as not to weaken the beams, and would probably be an advantage.

Comparative strength and cost of ligno-concrete and ferro-concrete beams.—The maximum bending moment of the three ligno-concrete beams 8 in. deep and 4 in. wide (Nos. 23, 24, and 25) was 5998, 6788 and 7938 lb.-feet. In the Proceedings of the

American Society for Testing Materials (1904, Vol. IV.) Mr. E. Marburg gives the results of testing a number of ferro-concrete beams 8in. deep $\times$ 8in. wide, which are compared with the ligno-concrete beam in Table XV. From this table it will be seen that the ultimate strength of the ligno-concrete beams was about the same as that of the ferro-concrete beam with 1% reinforcement.

TABLE XIV.

Beam No.	Age.	Ultimate Load at Centre of Beam.	Load producing first Crack.	Load at Yield Point.	Deflection at Yield Point.	B.M. for Deflection of 0.02in.
	Days.	Tons.	Tons.	Tons.	In.	Ton ft.
23	36	2.678	2.22	1.36	0.024	0.93
24	36	3.080	1.33	0.89	0.046	0.45
25	36	3.544	1.05	1.05	0.048	0.41

Considering the reinforcements on the tension side only, it will be seen that nine times as much pitch pine as steel is required to get the same ultimate strength. The only important difference in the cost of the beam will be the difference in price between the timber and the steel. A beam 8in. $\times$ 4in. and 4ft. 6in. long with 1% steel reinforcement will require 4.9 lb. of steel, and with pitch pine reinforcements 0.0885 cub. ft. of timber. Taking the cost of steel in the beam at 1.9d. per lb. and the cost of timber in the beam at 3.5s. per cub. ft., the cost of steel reinforcements would be 9.31d. and the cost of timber reinforcements 3.7d., a difference of 5.61d. in favour of ligno-concrete.

In cases where it is necessary to put in more than 1.2 % of steel, ligno-concrete could not compete with ferro-concrete, as the size of the timber bars necessary would be too large for convenient use.

CONCLUSIONS.

In the author's opinion, ligno-concrete cannot compete with ferro-concrete for all purposes, but he thinks that there is a large field for it for use in constructing bungalows, buildings for small holdings, floors, piles, posts, fencing, coast and river work, &c.

It has already been used for making fence posts from the author's designs. The cost of these works out at about 2.1s. per foot cube, or about 20% cheaper than creosoted yellow deal and 40% cheaper than English oak, and at the author's suggestion Dr. Owens, A.M.I.C.E., used it for constructing a short length of sea wall at Rottingdean. In Canada, as a result of the author's

TABLE XV.

Span.	Depth.	Depth to Centre of Reinforcement.	Width of Beam.	Reinforcement, percentage of total cross section.	Mixture of Concrete.	Age.	Load at which first Crack appeared.	Ultimate Load.	Deflection at first Crack.	Remarks.
Ft. 8	Ins. 8	Ins. 7	Ins. 8	1·17	1 : 2 : 4	Days. 30	lb. 5,625	lb. 7,600	In. 0·2972	Plain square steel bars (average of 3 beams).*
8	8	7	8	0·84	1 : 2 : 4	30	5,125	8,600	0·2505	Johnson indented steel bars (average of 2 beams).*
8	8	7	8	1·19	1 : 2 : 4	30	5,750	8,000	0·2876	Ransome twisted steel bars (average of 2 beams).*
8	8	7	8	0·92	1 : 2 : 4	30	5,375	6,800	0·2459	Thacher corrugated steel bars (average of 2 beams).*
4	8	6·25	4	9·00	1 : 1½ : 3	36	3,453	6,900	0·2670	Pitch pine rods (average of 3 beams).
8	8	—	8	—	1 : 2 : 4	30	—	720	—	Beam not reinforced*
4	8	—	4	—	1 : 1½ : 3	36	—	560	—	Beam not reinforced.

* *Vide* Proceedings of American Society for Testing Materials, 1904, Vol. IV.

investigations, the Pacific Coast Construction Co., of Victoria, British Columbia, have formed a special ligno-concrete department, and have made a large number of slabs for building houses. They have built four houses, and at the present time the company have contracts in hand for over twenty houses of the bungalow type, all of which are to be built with ligno-concrete slabs. These slabs are made to a standard size, 8ft. $\times$ 2ft. $\times$ 3in. or 1½in. thick. If the slabs are made 1½in. thick two of them are used to form a hollow wall. No slabs have shown the slightest signs of cracking, although transported by rail only three weeks after casting.

In conclusion, the author desires to acknowledge his indebtedness to Prof. C. A. M. Smith, M.Sc., for some valuable assistance and advice, and for making some of the tests on beams at the East London College.

DISCUSSION.

The President said that he had great pleasure in moving a vote of thanks to Mr. Gerald Case for the very instructive paper which he had just read.

The vote of thanks was unanimously agreed to.

Mr. D. B. Butler said that the author had evidently spent much time and pains in making researches. A paper of this kind, he thought, always deserved greater recognition than one which was either a mere dissertation on acknowledged facts or an expression of opinion.

With regard to Fig. 1, representing work done in America, where a pile had been cased in concrete and then again in timber, the concrete being moulded round the pile, it would surely have been cheaper and much quicker to have made a ferro-concrete pile.

On page 84 the author referred to the comparative prices and strength of reinforcements of timber and steel respectively, and said, "Roughly speaking, mild steel is about eight or nine times as strong as timber but ten to fifteen times as expensive." If the two extremes of those figures were taken, there would not be very much margin in favour of timber.

He should like to ask the author why the dimensions, though they were all in the metric system, were in odd fractions, instead of even numbers, which seemed to complicate the calculations needlessly. On page 85, for instance, the author gave the dimensions of test pieces, as 10.3 $\times$ 3.88 $\times$ 3.88 cm., while on page 89 they were 11.4 $\times$ 3.8 $\times$ 3.8 cm. It seemed that the experiments could have been much more easily compared if the test pieces had all been made of the same size.

On page 98 the author referred to different coatings with which he treated the various kinds of wood to prevent them from

absorbing water. Some of the material he painted with white lead paint, and some apparently were varnished, and others were simply soaked in a special wood preservative. It seemed to him (Mr. Butler), that to paint a wood used for reinforcement would thoroughly nullify the effect of the reinforcement, since the cement could only adhere to the paint, and the paint having very little adhesion to the timber, there would be little or no adhesion of the concrete to the timber.

Speaking broadly and taking the paper as a whole, it seemed to him, that the main difficulty in adopting the timber method of reinforcement would be to avoid what really seemed to happen in many cases; that is, either the cracking of the concrete by the swelling of the timber, or the loss of adhesion between the timber reinforcement and the concrete, in consequence of the subsequent shrinkage of the timber. These things would altogether destroy the effect of the reinforcement. For instance, on page 98 near the bottom it was said, "All the blocks cracked except those with the teak rods in them," and on page 100 it was said, "In both cases the rods split the blocks."

He would here like to make a remark, personal to the author, with regard to certain wording on page 103, in which the B.E.S.C. specification was referred to; this puzzled him for a long time on reading the advance proofs. He wondered whether these initials, could possibly refer to "Brighton Electric Supply Corporation" specification, since the experiments were made at Rottingdean. It never occurred to him for a moment that the letters meant the "British Engineering Standards Committee's" specification. He was chiefly interested in testing cement, and it was always the custom among most cement manufacturers and users to adopt the short method of describing that specification as simply "B.S.S." *i.e.* British Standard Specification.

On the whole the experiments seemed to have been rather limited in time. For instance, the experiment as to the absorption of moisture by the timber occupied only three days, while the maximum time allowed seemed to have been from ten to fourteen days. This appeared to him to have been hardly long enough to prove whether the timber inside the beam would either absorb moisture from the concrete and become swollen, or contract in consequence of evaporation, and thus affect the strength of the beam.

On page 106 the author mentioned that the cement was "chamber" cement B.E.S.C. specification. He would like to know whether that meant the difference between chamber kiln cement and rotary kiln cement.

Mr. Case replied in the affirmative.

Mr. Butler (resuming), said that the crux of the whole question was in pages 105 and 107 in which it was admitted that "In practically every case there were signs that the reinforcement has slipped through the concrete."

This appeared to show very clearly that the adhesion between the concrete and the timber was very slight and insufficient. It was well known that the whole *raison d'être* of reinforcement was that there should be strong adhesion between the reinforcing body and the concrete, and if, during the test, the adhesion failed, that fact of itself clearly showed that the reinforcement was of little or no use.

On page 110 the author referred to slabs being made of ligno-concrete for the building of houses. Here, again he (Mr. Butler) thought that ligno-concrete would compare very disadvantageously with ferro-concrete in regard to its fire-resisting properties. What would happen if a ligno-concrete structure were exposed to fire he, for one, would not like to say.

Mr. W. Noble Twelvetrees thought that the idea of timber reinforcement was quite a novel one, for, although timber had been used inside concrete, he was not aware that it had ever been used as a material for reinforcing beams, and this, he took it, was the chief point which the author had in view. When concrete reinforced with steel was first introduced into this country, it was naturally looked upon with a great deal of prejudice, and there were a great many sad predictions as to what would happen when the steel rusted away. But steel had been used for a good many years alone, and no one seemed to have been afraid that it would decay very suddenly. Concrete also had been used separately for a great many years, and therefore it was a little difficult to understand why there should have been prejudice against the two materials when they were used together. To-day Mr. Case had brought forward another material as reinforcement, and perhaps some engineers might be inclined to look with a little suspicion or prejudice upon the use of a new material or the new use of an old material. He confessed that, although he did not like to express any prejudiced view, he was not quite in favour of timber as reinforcement, but still he thought that the idea should have fair consideration.

One thing which might be urged against timber was that it was a material of somewhat variable properties, and in that respect it was not quite like the bars of steel which came from the same rolling. Such bars of steel might be expected to be practically uniform; but they did not know what would be the case if they cut up a plank of wood into a lot of little sticks, for they could not possibly be sure that each piece would have the same power of resistance. He did not say this to condemn

the use of wood, but certainly each piece of wood that was used would need very careful inspection.

The author had foreseen some of the objections as, for instance, the swelling of the timber and the consequent destruction of the concrete. That was an objection which had already been experienced in the United States. He read in the *Engineering News* two or three years ago of timber which had been used in concrete wharves in San Francisco and which had cracked the concrete very badly. Perhaps that was dry timber or timber which had not been swelled by soaking in advance. There had been considerable correspondence in the *Engineering News* on the subject, and some engineers said, "Never on any account use timber inside concrete."

Another point was the possibility of dry rot being inside the timber. This might not often happen, but, if dry rot were present, the boxing up of the timber in concrete would not prevent the ultimate decay of the timber. The presence of dry rot, however, was a matter which ought to be discovered beforehand.

The point which Mr. Butler had made with regard to adhesion seemed to be rather an important one. The rods which had been used by the author certainly did not seem to adhere so well to the concrete as might have been hoped, and the author had told them that Professor Smith had said that the adhesion was not quite good enough; but that was merely a practical point which might be got over in some way, either by the notching of the timber of which the author had spoken, or by the making of some kind of anchorage at the ends of the rods.

On page 107 they were told of a large crack suddenly occurring with a loud report like that of a pistol. One of the advantages of the ordinary reinforced concrete was that failure was not sudden. But the case of failure of the timber reinforcement mentioned in the paper showed that the failure was quite a sudden process. In the case of concrete reinforced by steel one got notice of the failure beforehand by the cracking of the surface and, perhaps, the falling off of the little bits of concrete before a beam would absolutely fail. If beams reinforced with timber were going to fly to pieces and make a report like a pistol, it would be alarming and unpleasant, especially for people who might be standing on them.

Other objections seemed to have been foreseen by the author, who had gone to a great deal of trouble in making tests with the object of seeing how far his novel idea would be of practical value. It had been remarked by Mr. Butler that the tests were not of long duration, but that could be quite understood, because if the author had spent several years in making tests they would not have had the pleasure of seeing him present that evening.

The tests which he had made had been valuable in throwing light on the use of timber for reinforcing concrete.

Professor C. A. M. Smith said that he was pleased to be able to add a few words about tests which he had made in conjunction with Mr. Case about two years ago. Events which had happened since made him feel that a subject like this ought to be approached with an open mind. Unfortunately English engineers frequently negatived anything new simply because it was new. It had been said that ligno-concrete was not a new thing. That was true, for timber reinforcement was used in the old wall of China ; but in that case the wood was embedded in the other material in a rather haphazard fashion.

He would strongly emphasise the remark of the last speaker that in using timber they were not at all sure with what they were dealing ; but the same was the case with all metals except steel, which was extraordinarily uniform. A great difficulty was experienced in the use of other materials, and especially non-metallic ones, through manufacturers not having fully appreciated how very non-uniform materials in general were. Concrete itself, was not very uniform and its properties depended greatly upon the way it was mixed, etc. The difficulty of want of uniformity in timber was one which might be overcome by very careful selection. Perhaps, the greatest usefulness of the paper lay in the fact of its being a record of certain definite tests.

The first speaker alluding to Fig. 1. remarked that the beam shown there might as well have been reinforced with steel. He (Prof. Smith) did not speak as a commercial man, but it seemed to him that that would obviously depend upon the relative prices of timber and steel. He did not think that anyone would venture to suggest that timber reinforcement would be applied in London for building a place like the General Post Office. But timber reinforcement was capable of wide application in places where timber was plentiful and the great cost of carriage would make steel expensive.

The conclusions contained on page 102 of the paper were, he thought, very fair. The paper showed what to avoid ; a most useful thing in engineering work. The author gave records of careful tests which were attended with a certain amount of failure. It was upon failures that they built success. The author had shown a most straightforward character indeed in pointing out the weaknesses of the material with which he was dealing, for many authors covered up the weaknesses exposed by their tests. He could honestly say, having made some of the tests for the author, that if he had wanted to do so he could not himself have written anything more damaging with

regard to the tests than the author, in most praiseworthy fashion, had written in the paper.

He took it that the author intended next to grapple with the question of getting a positive grip of the concrete on the timber. He himself was not quite sure on the question of beams except in special cases, but he thought that there was a considerable future in the other directions which the author had outlined.

On page 108 the author put down in Table XIV. "Load at yield point." The trouble was to know exactly what to call the yield point." This depended on the personal equation of the observer and on many other things. He would remind the audience that the yield point of concrete was most indefinite.

He felt that the author had given him (Prof. Smith) far too much credit, because the whole idea of the tests and everything connected with the matter originated entirely with the author. He considered that, even if there were no future for ligno-concrete, the work which the author had done in ascertaining the reliability and behaviour of timber under various circumstances was such that Mr. Case well deserved the congratulations of the Society for bringing the subject to their notice.

Mr. F. J. Gray said that at Brighton the author had very kindly shown him specimens of the reinforcement for his ligno-concrete beams, and had explained how he was conducting his tests. When he first heard several years ago of the author's experiments he was inclined to look upon them as being more of academic than of practical interest; but when he learned the results of some of the tests, he realised that Mr. Case had hit upon a combination of materials which, from the point of view of economy, would prove useful in building construction. The criticism of one speaker, he ventured to say, was rather misplaced, when he compared ligno-concrete with ferro-concrete for all purposes. He did not think that the author claimed the application of ligno-concrete to every purpose to which ferro-concrete was applied. Posts, fencing, walls and the like, having somewhat small dimensions and being subjected to no great stresses, would be probably the principal applications of ligno-concrete; and, of course, the system would be especially useful in countries where timber was abundant and steel difficult to obtain.

Mr. Henry C. Adams said that the series of experiments conducted by the author was most valuable, and the result had been given in a very clear form. On looking at the paper generally, he (Mr. Adams) did not think that the author had made out a case for the use of ligno-concrete at present, but

undoubtedly the information contained in the paper would help towards that end, and the paper was one which, he thought, they ought to put away for reference in the future. A lot of experiments made ostensibly to ascertain the classes of wood to be used went to show principally that wood expanded when it was wet, which was, of course, more or less obvious before, and that when it was desired to use timber that tendency to expand could be overcome by soaking it before use.

He pointed out that the experiments were spread over a very short period, especially having regard to the fact, as Mr. Case told them at the end of his paper, that timber went on taking up water for 200 days. If, in addition to weighing the timber, Mr. Case had extended his experiments by measuring the expansion of the timber, and given the figures, the utility of the information would have been very much increased.

He had not gathered from the paper how thick the concrete was round the timber when the absorption of the encased timber was ascertained. It seemed from one of the figures that it was about two inches thick. That was very thin indeed, and concrete only two inches thick would be very porous. There was another point to consider with encased timber, namely, that if the timber was going to absorb moisture from the concrete, it would weaken the concrete immediately abutting against the timber, and that, of course, would be detrimental to the structure.

One of the experiments showed that timber absorbed water or increased in weight more when it was soaked in sea water than when it was soaked in fresh water, but it was rather difficult to see why that should be so. It appeared to him that timber soaked in sea water might take up certain salts, or that such salts might be deposited on it which would be weighed in afterwards, in which case the actual absorption of water by the timber would probably be the same in both cases.

He thought that it was at least debatable as to how dry rot in timber occurred, for it occurred in so many ways. The timber might be infected when it was used, or it might become diseased after. A few years ago a large floor was being laid, and some small timber plugs were put in for securing the wood blocks. Nearly all the plugs that were embedded in the concrete were attacked by dry rot, which spread to the blocks and the whole floor had to be taken up and relaid.

It had been suggested that ligno-concrete might be used in sea work to protect the piles. But timber piles were fairly well in the sea, especially if the water were sandy and dirty, for, apparently, the sand which rubbed against the timber rubbed off the insects which were attacking it, and the timber lasted longer than when it was in clear water. There was a lot to be learned yet as to the action of concrete in sea water, and,

unless the concrete was a very strong mixture and was well made, it would rot and fall to pieces, and the timber would be exposed.

The experiments had amply demonstrated the fact that the adhesion between the timber and the concrete was very small, but if they were extended so as to give the actual value of the adhesion of the concrete to the wood, that would further add to the utility of the experiments.

There was one other point which, perhaps, Mr. Case might further investigate, and that was as to whether increasing the strength of the concrete, by making a stronger mixture, would not avoid some of the cracking, which occurred in consequence of swelling in the timber. Thanks were due to Mr. Case for his paper which was well worthy of being included in the Transactions of the Society.

Mr. R. J. Simpson said that on page 110 the author referred to ligno-concrete slabs 8ft. by 2ft. by $1\frac{1}{2}$ in. thick used for building purposes. He would like Mr. Case to give particulars of their construction, how they were reinforced and the cost per slab.

Mr. H. Conradi said that as far as his experience went he would on no account use concrete reinforced with iron or steel in any kind of engineering work where different stresses occurred. In steel or iron they had to deal with fibres but in concrete they had to deal with molecules. The fibres shifted their position under varying forces, while the molecules got crushed, and there was no cohesion or affinity between the fibres and the molecules of the two materials so widely differing in their composition. Where only compression had to be met they might use concrete reinforced by steel or iron, as in plain architectural or masonry work, retaining walls and abutments, but not otherwise.

Mr. R. W. A. Brewer wished to know when the author considered that a condition of stability was arrived at in work of this sort. By that he meant did the author consider that the timber which was embedded in the concrete should be maintained in a state of saturation or maintained in a state of dryness; or should it be saturated to a certain extent to give the adhesion to the concrete, and then sealed up and prevented from either receiving or giving out more moisture? It appeared to him that, in two materials whose expansion and contraction were so different as those of the two materials which they had now under consideration, it would be impossible unless some preventive action were taken, to maintain any degree of cohesion between them at all times throughout the whole life of the structure.

Mr. F. G. Bloyd remarked that the author had said that one experiment was made with a properly creosoted timber. Would he state to what degree the timber was creosoted; that is to say the pressure? He thought that the author would agree that, the more thoroughly the timber was creosoted, the smaller would be the amount of water which would be absorbed. The second point was with regard to the testing of the block mentioned on page 101. The author had not said whether the block was immersed in water or whether it was exposed to the open air. Had the author considered at all the effect of temperature on these blocks? He took it that if the block in question were put into the sun and wind there might be a different effect from that which would be produced if it had been kept in a closed chamber.

On the other point about which he wished to speak, Mr. Adams had forestalled him, and that was the effect on the concrete produced by the timber absorbing a certain quantity of water. He rather wished that Mr. Case could have given them some test of the concrete himself.

REPLY.

Mr. G. O. Case replying said that Fig. 1, allusion to which had been made by Mr. Butler, was merely given to illustrate a method often adopted in the construction of harbour works in America and was referred to chiefly to show that timber was preserved in concrete. He quite agreed with Mr. Butler that the adhesion would be impaired if the timber rods were painted. He did not think that painting would do at all, and he did not advocate it.

Many of the speakers had dealt with the question of adhesion. He certainly agreed with them that it was a weakness inasmuch as the beams eventually failed owing to the reinforcements slipping, but by notching the timber rods the adhesion might be increased to a great extent. He did not think that the question of adhesion was a serious one. If they would look at the table on page 108, they would find that, although the beams failed eventually through lack of adhesion, the first crack did not appear until there was an average load on the ligno-concrete beams of 3453lb. That was a very considerable load and compared very favourably with the load which concrete reinforced with steel would withstand.

Mr. Butler had asked why the experiments for the soaking of the timber covered such a short period. The paper did not contain all the experiments which he (Mr. Case) had made. Experiments were, in fact, made over very long periods; but dry timber rods when embedded in concrete absorbed moisture

for only about three days, and it was not therefore considered useful to give results of experiments over a longer time. Rods which were embedded in concrete would take up water for three or four days, and then they would give up water and regain their original weight. It was thought by Mr. Butler that one of the chief dangers was that the concrete might crack, but he (Mr. Case) had not found any cracks in cases where the rods were soaked before being embedded in the concrete. The soaking of the rods quite overcame any danger of the ligno-concrete cracking.

No tests had been made with regard to the fire-resisting power of ligno-concrete, but he (Mr. Case) hoped that such tests would be made before long.

It had been pointed out that there was a considerable variation in the results of timber tests. Previous to 1890 the tests for timber varied very widely, but since then the experiments made by Prof. Johnson had shown that the variations were due largely to the different percentages of moisture in the wood when the tests were made. If they ascertained the actual percentage of moisture in the wood the strength could be very fairly and accurately found out. In ligno-concrete the rods used were of a comparatively small size, and it was easy to see if there were any flaws in them.

With reference to the question of dry rot inside the concrete, the Australian hard wood Jarrah had been embedded in masonry for many years, and there was no appearance of dry rot, but he thought that when soft wood was used it might be advisable to creosote the rods. He did not think it possible for dry rot to occur if creosoted rods were used. With regard to No. 25 beam, the one which cracked suddenly, that beam was reinforced differently to the other beams and it was the only one out of about thirty which did crack suddenly. In the others the cracks were very small and they gradually opened.

Mr. Twelvetreets, interposing, asked whether the wood snapped.

Mr. Case answered in the negative. The wood did not break in half, but it cracked.

He quite agreed with Professor Smith that timber was not so reliable as steel, but he thought that if rods were carefully selected they would be as effective as steel rods for many purposes and much cheaper.

Mr. H. C. Adams had asked how much concrete there was round the small test blocks. There was about $1\frac{1}{2}$ or 2 inches. He did not agree with Mr. Adams's explanation of the rods taking up more sea water than fresh water. Mr. Adams suggested that if the concrete were made stronger it would not be so

liable to be cracked by the dry timber rods, but he (Mr. Case) had found that, the stronger the concrete was made, the greater was its liability to crack. In his (Mr. Case's) opinion this was due to the greater alkalinity of the water.

Mr. Simpson had asked how the inch and a half slabs used for house building in Canada were reinforced. They were reinforced by a half inch fir rods placed in the centre of the slabs, the rods being connected by wires.

One of the speakers asked whether the timber dried inside the slabs after they were made. He had examined a number of beams and posts after three, four and six months, and he found that, although the wood was soaked when it was put in, it was apparently quite dry after three months.

Mr. Bloyd had asked about the creosoted timber. The specimens with which he (Mr. Case) experimented were creosoted by Messrs. Burt, Boulton and Haywood. He did not know what amount of creosote was put in, but it was the maximum amount.

A question was raised as to whether the beams would be affected by being seasoned in the air. The answer was that all the beams which he tested were seasoned in the air. None of them was seasoned under cover.

6th May, 1912.

JOHN KENNEDY, PRESIDENT,
IN THE CHAIR.

INTERMITTENCY : ITS EFFECT IN LIMITING ELECTRIC TRACTION FOR CITY AND SUBURBAN PASSENGER TRANSPORT.

By WM. YORATH LEWIS, A.M.I.Mech.E., A.M.I.E.E.,
M.Am.Soc.Mech.E.

INTERMITTENCY is a characteristic common to all systems of passenger transport in general use. Intermittency may not be an objectionable feature in the case of a trunk line railway as regards its long distance trains, but its effect upon urban and suburban passenger transport, as instanced either in ferry, railway, tram or bus facilities, is extremely detrimental. In city, urban and suburban service the inherent nature of the traffic is that of a continuously flowing stream varying considerably in volume at more or less definite periods of each day, maximum density occurring at morning and evening during what is known as the "rush" hours. Usually the flow is along well defined and regular channels between certain localities, but periodically the traffic stream is diverted and is often augmented in volume, according to special circumstances. The means for dealing with this human stream should, consequently, partake so far as is practicable, of a *continuous* as distinguished from an *intermittent* nature.

Passenger traffic is always demanding improved facilities,* and each improvement is readily appreciated. Amongst the most important requirements may be mentioned prompt service, ready access, comfort, rapid transport and *low fares*. Each development is undoubtedly of benefit to the community, as also, generally speaking, to the whole of the previously existing systems, because of the growth of the travelling habit which is thereby encouraged. All existing facilities are being more and more severely taxed by reason of the steady growth of population, expansion outwards towards the suburbs, with resulting increase not only of number of journeys per head of population,* but also of the average length of journey. Those engaged in the operation of transportation facilities are endeavouring to

* See Royal Commission and Board of Trade Reports on London Traffic.

meet the demand by intensifying their service. They are endeavouring more and more to approach the conditions of a continuous service, but they are seriously baulked by the intermittent character of their systems, in some of which the commercially attainable limit has already been reached.

Now what are these detrimental results of the periodic-service systems in existence? The result of damming a human stream moving at the rate of 3 m.h.*—if the volume is 4 abreast, 6ft. apart, and if the period of check is only one minute—consists in the accumulation of a crowd of $\left(\frac{88 \times 4}{2} =\right)$ 176 people :

meaning discomfort and a serious time loss of more than one minute, because of the time required to enable this detachment to board the conveyance, pending the arrival of which it had accumulated. Obviously, if instead of interrupting this human stream, accommodation could be provided with a capacity of say $\left(\frac{176}{60} =\right)$ about three seats per second passing through the station at a speed sufficiently slow to enable the passengers to step on or off the cars, all delay and congestion would be eliminated. There would be neither the need of a station platform, nor of trains long and large enough to accommodate the assemblage. To meet the requirements, the present method of dealing with the situation consists in providing a distinctly intermittent service of trains of limited capacity, which are run at sufficiently short intervals to ensure the passing of say $(176 \times 60 =)$ 10,560 seats per hour through the stations. This involves, with 50-seat cars and say 6-car trains, $\left(\frac{10560}{50 \times 6} =\right)$ 35 trains per hour.

The Metropolitan District Railway of London now runs over a section of its lines during the rush hours 40 trains per hour in each direction. Assuming that these trains are composed of six 50-seat cars, their capacity is $(40 \times 6 \times 50 =)$ 12,000 seats per hour. The length of the train is $(6 \times 50 =)$ 300ft., necessitating platforms about 400ft. long. The corresponding time-interval between the trains is $\left(\frac{60 \times 60}{40} =\right)$ 90 secs. The schedule speed is about 15 to 16 m.h. and the stations average half a mile apart, whilst the average stop at each station is about 20 secs. Now to operate such a service of trains, electric traction alone is capable. The following investigation of the somewhat elaborate provisions that have to be made with an electric train service to meet such requirements, reveals many

* NOTE.—Throughout this paper the following abbreviations are used :
 Miles per hour is abbreviated to m.h.
 Miles per hour per second is abbreviated to m.h.s.
 Miles per hour per sec. per sec. is abbreviated to m.h.s.s., etc.

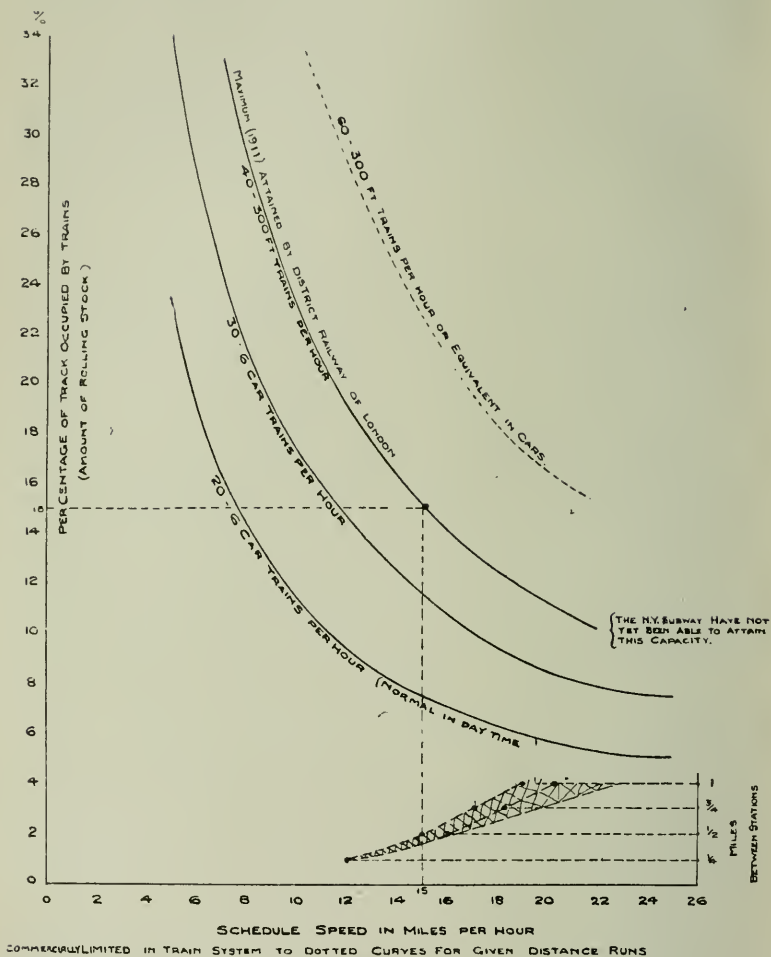
serious objections, and indicates that the commercial limitations are entirely traceable to "Intermittency." As the trains are made up of six 50ft. cars, the aggregate length of train passing hourly through a station amounts to :—

$$\left(40 \times 6 \times 50 = \right) 12,000\text{ft. or } \left(\frac{12,000}{5280} = \right) 2.28 \text{ miles.}$$

Although in some instances a schedule speed of 16 or even 17 m.h. can be maintained on such services, 15 m.h. is a more representative value, and will at any rate serve for illustrative purposes. Thus we see that only $\left(\frac{2.28 \times 100}{15} = \right)$ 15.2 per cent. of the track is occupied by trains, as shown by the curve in Fig. 1. If this percentage could be doubled during the rush hours, what would be the result? London's underground railways have cost one half to three quarter million pounds or so per mile, and much the greater portion of this outlay is represented by the tunnel structures, the permanent way and the stations. Consequently the more intense* the use to which this extensive property is put the greater will be the capacity and the lower may be the fares charged, provided that the increased traffic obtained is commensurate with the increased accommodation provided. It is well known that the present average tube fare of 0.6d.† per mile is inadequate to yield reasonable

* For short haul passenger trains, *i.e.* for passenger trains making frequent stops, practice has shown that long trains are not economical, and a train of six 50ft. cars is representative of the upper limit. Counting the trains passing westwardly through St. James's Park Station of the District Railway about 5.30 p.m. on October 25th, 1910, of 16 consecutive trains 3 had 7 cars, 9 had 6 cars and 4 had 4 cars, while on the New York Subway, the local trains comprise five cars. For travelling a short distance a traveller would avoid walking the 400 ft. from the end of an 8 car train to the platform exit, but for a longer journey this would be less of a consideration. On page 26 of his Report No. 4 on the New York Subway (May 22nd, 1908) Arnold recommends increasing the express trains on the Subway from the present eight cars up to ten cars, but he only proposes to increase the local trains from five cars to seven cars, notwithstanding the tremendous overcrowding with the present service in the New York Subway. For a 2-stop-per-mile service, a 6-car train is the largest which could be taken as representative of best present practice. The circumstance that on the District Railway certain *non-stop* trains comprise 8 cars, does not invalidate the above conclusion. With high-speed frequently-stopping trains, the decreased space interval between successive trains, with long trains, is a serious consideration when the service provides 40 trains per hour in each direction.

† On page 7 of Report 7 (Dec. 31st, 1908) Arnold states :—" To make a comprehensive Subway System pay a fair return on the investment, the income from passenger traffic should average about one cent. (0.5 penny) per passenger mile." But Arnold, dealing with the New York standard, acquiesces in the provision during rush hours, of but one seat to 2 or 3 passengers carried. Under these conditions 0.5d. per passenger mile yields a larger revenue per seat mile than 0.6d. per passenger mile with the better seating accommodation at present furnished by London's underground railways.



AMOUNT OF ROLLING STOCK IN SERVICE
PERCENTAGE OF TRACK OCCUPIED BY TRAINS

FIG. 1.

dividends, and yet either a higher effective speed from street to street, or an appreciably lower fare would be necessary in order to divert traffic to the tubes from the competing surface traffic.

With the present rush-hour maximum of forty 6-car trains in each direction, a considerable proportion of the passengers are "strap-hangers." Obviously then, unless more than forty 6-car trains can be run per hour, it would be futile to reduce the fares. But if, to fix ideas, we assume that a 20 per cent. reduction in the fares charged on the tubes, would divert traffic from the busses and trams, to the extent of doubling the number of tube passengers, the gross receipts would be increased by sixty per cent. (since $2 \times 0.8 = 1.6$) and the corresponding net receipts would be simply increased by the costs incidental to the running of more trains per hour through the stations (at the same schedule speed) to the extent of the necessary additional rolling stock, and by the greater outlay for power and for wages of train crews and of station attendants, a much greater return could be earned on the large capital investment represented by the tube structures and the stations.

INTENSITY OF SERVICE.

At first sight it does not appear that it should be impossible to have a great deal more than 15% of the track "occupied" by trains,* but an examination will reveal very positive limitations. At a schedule speed of 15 m.h. (22 f.s.) thirty stations, one half mile apart, are passed through per hour and as there is a 20 sec. stop at each station, the train is at rest for ($30 \times 20 =$) 600 secs. out of the 3,600 secs. in the hour, consequently the mean speed (or as it is usually called, the average speed) of the train while it is in motion is $\left(\frac{3600}{3600 - 600} \times 15 = \right)$ 18 m.h. To attain this average speed the train must be accelerated from rest up to a crest (*i.e.* momentary maximum) speed of about 24 m.h. at some point between the stations, and then decelerated until it comes to rest at the next station.

Fig. 2 shows a speed-time diagram for such a train-movement, and in Fig. 3 a succession of corresponding distance-time diagrams are drawn for two trains departing from stations at intervals of 90 secs. from each other. In Fig. 3^a the distance between

* Regarding the intensity of service to which a railway route can be put, consideration should be given to the number of seat-stops that can be made per hour per thousand pounds of capitalisation, or taking another point of view, the intensity of service to which the expensive property comprising the tunnels, tracks, etc., can be put, may be judged by the number of square feet area required per seat stop per hour. The number of seat stops per hour is a function of the "earning power."

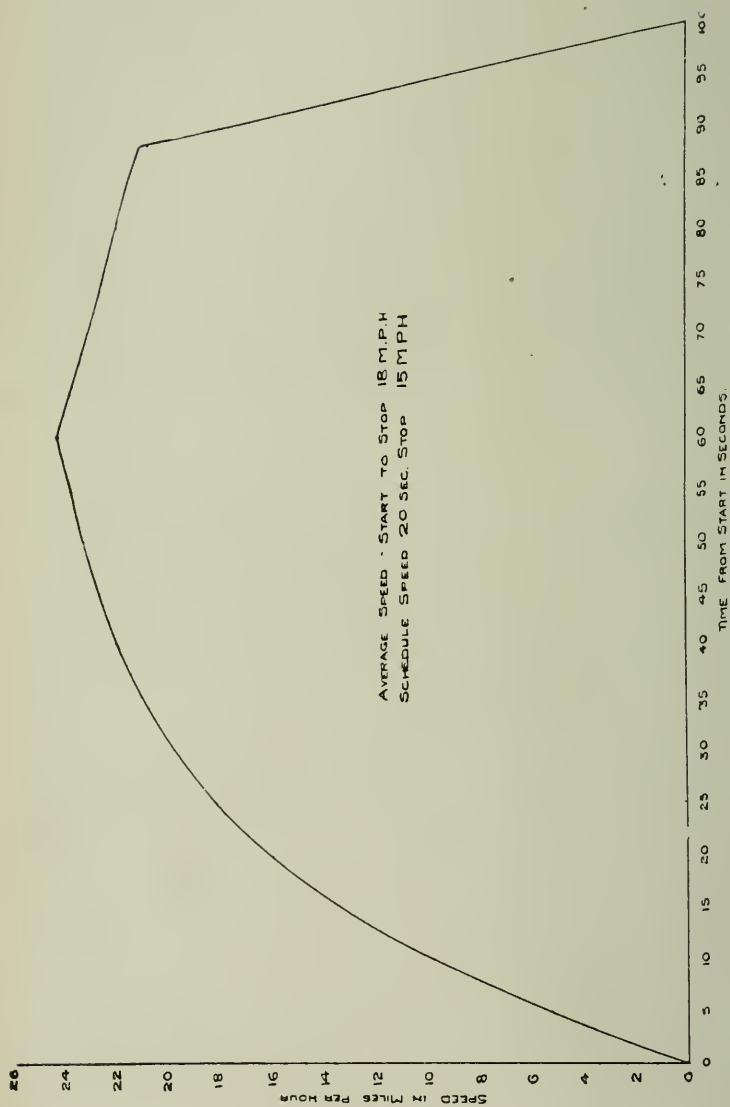
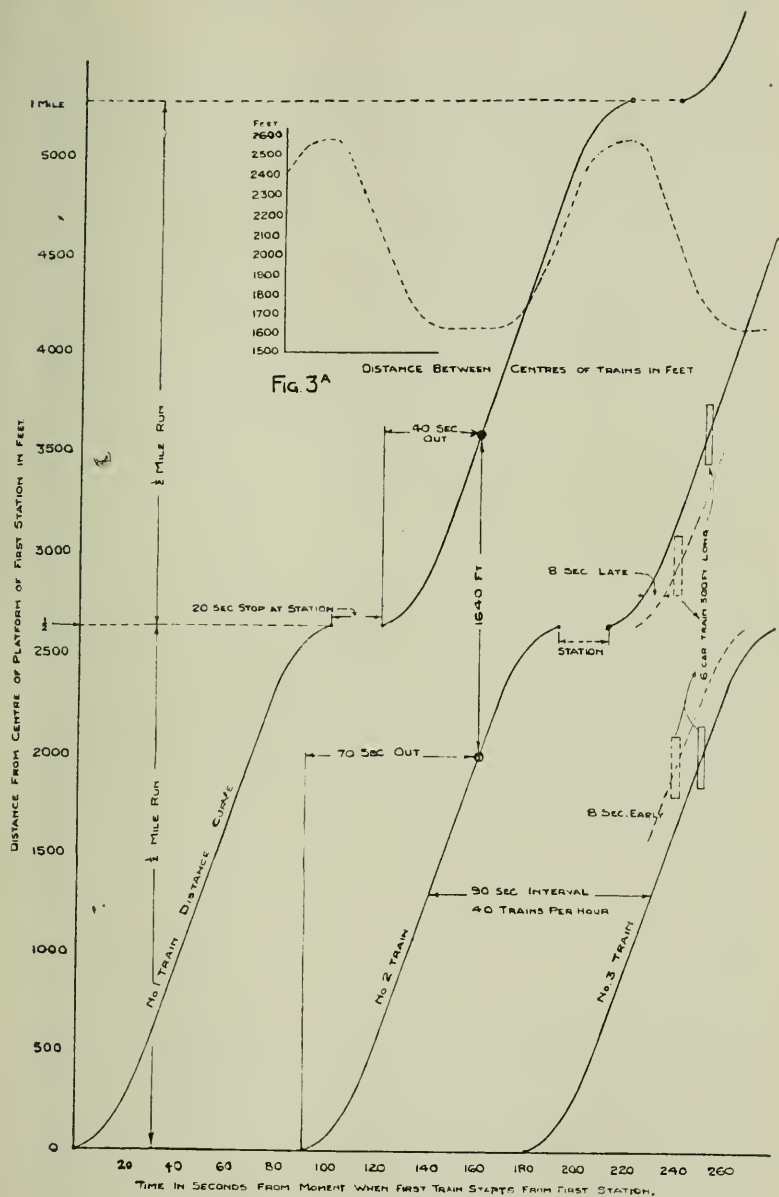
TYPICAL SPEED TIME DIAGRAM $\frac{1}{2}$ MILE RUN

FIG 2



TRAIN MOVEMENT CURVES

Fig.3

these two trains is plotted and it will be seen that the distance varies periodically from a maximum of 2,600ft. down to a minimum of 1,640ft. An examination of Fig. 3 shows that the instance of minimum distance between trains, corresponds to 40 secs. from the start of one train and 70 secs. from the start of the other. Referring to Fig. 2 the corresponding speeds at this instant are 22 and 23 m.h. respectively.

Far from being practicable in actual service to preserve these times and distances to the second, the probable departure from the theoretical time is doubtless about 5 seconds. If the train in front is 5 seconds late, and the trains behind is 5 seconds early, then taking the mean speed of the trains as 22.5 m.h. at the moment of minimum distance between them, this aggregate of 10 secs. departure from the desired headway will decrease the minimum distance between them by $(10 \times 22.5 \times 1.467 =)$ 330ft., and this minimum distance thus becomes $(1640 - 330 =)$ 1,310ft. This is the distance between the centres of the trains. The clear distance is $(1,310 - [6 \times 50] =)$ 1,010ft. The substitution of 12-car for 6-car trains would further decrease this minimum distance to $(1,010 - [6 \times 50] =)$ 710ft., and this is one of several objections to longer trains for such a service.

Now it will be recognised that with two 6-car trains each travelling at a speed averaging 22.5 m.h. and with only 1,010ft., intervening space, considerable signalling apparatus is essential for the maintenance of such a service, inasmuch as successive trains may at recurring intervals traverse given points in the line within periods of 31 secs. of one another. To negotiate such conditions, the signalling apparatus has been reduced to an automatic system, reducing the human element to a minimum, and though the initial and operating cost of this accessory, demanded by the intermittent character of the electric train system, is a considerable item in the initial and operating costs, one cannot but admire its remarkable reliability and effectiveness. The resources of the signal engineer's ingenuity are, however, taxed towards the extreme in meeting these requirements, and it is highly improbable that much further progress can be made in this direction (see 2nd footnote page 129). It has been suggested by Arnold, that by employing island platforms, and receiving and despatching successive trains at opposite sides of the platform, one train may enter the station even before its predecessor has departed.*

* By this and other means, Arnold estimates that a subway could be built for providing a service of 60 trains per hour in each direction, *i.e.* one train per minute. At present however, the New York Subway, which has been the subject of reports in which Arnold makes this proposal, is striving in vain to maintain a 90 second service for its express trains, and it does not aim even at this standard for its local trains. But after many years of endeavour several of the underground railways have succeeded in providing during rush hours, a service of forty 2-stop-per-mile

Such a proposal indicates the acuteness of the situation. It would, however, entail enormously increased capital outlay at stations. It may reasonably be concluded therefore that the limitations of the electrically operated train system are reached in the attainment of a 15 to 17 m.h. 2-stop-per-mile service with forty 6-car trains in each direction per hour. The maximum carrying capacity of such a railway over such a route, is limited to approximately $(40 \times 6 \times 50 =)$ 12,000 seats per hour.

CAPACITY, SCHEDULE SPEEDS AND AMOUNT OF ROLLING STOCK

The intermittent character of the train-system service is thus the factor limiting the schedule speed, and consequently the capacity, and in limiting the former it also necessitates a larger amount of rolling stock than would be necessary for the same capacity, were it possible to maintain higher schedule speeds. Mr. Chapman in operating the G.N.P. & B. Rly. found that with a 16.1 m.h. scheduled service, two less trains were required to provide an aggregate capacity of 40,000 train miles per week than were required for the 14.8 m.h. service.

By reducing the number of stops at stations, and otherwise making refinements which involve difficulties and increased cost of operation,* schedule speeds slightly higher than 15 m.h. with smaller trains, can be attained when the stations are slightly under $\frac{1}{2}$ mile apart, as for instance on the G.N.P. & B. Railway, where for the trains stopping at all stations the average run is 0.45 mile, and the schedule speed is 16.1 m.h. But 15 m.h. is more representative. Indeed on the C.L.R. the average distance between stops is 0.48 mile, and the schedule speed is only 14.5 m.h. It would manifestly be impracticable and commercially impossible to negotiate any such intensity of service, as that on the present tubes and underground railways of London, if the stations were to be located at an average distance of only $\frac{1}{4}$ mile apart; although from the view point of traffic attractiveness and public convenience, stations at these shorter intervals are highly desirable in the case of city and

trains in each direction per hour. Arnold points out that the difficulties of attaining to a given number of trains in each direction per hour are greater the shorter the runs between stops. Thus it is easier for an express service than for a local service.

It is understood that the District Rly. contemplates, in order to get a 50 train per hour service, adopting this costly plan by making at Charing Cross Station an additional platform of the island type. A somewhat similar arrangement has been recently adopted at the Mansion House Station.

* Headway is governed either by (i.) Limiting features of the signal system *en route* between stations or (ii.) Limiting features within the station blocks, the chief of which is the delay caused by loading and unloading the intermittent trains. In the New York Subway the latter controls (see Arnold's Report on New York Subway.)

urban routes. Here again the intermittent characteristic proves to be the bugbear of the electric train system, but still further detrimental effects may be indicated. The maintenance of an intense service (say 12,000 seats per hour in each direction) has been shown to involve the problem of starting a heavy mass in the nature of a long train, accelerating this mass to a high speed and then retarding it to rest 40 times per hour. With the electric train system this is only rendered possible by providing equipment of a very costly and complicated nature, involving much skilled attention and a seriously considerable element of human labour for its operation and control. Furthermore a system involving the transportation of passengers in *crowds* instead of in *streams*, requires not only long but also very bulky trains, which can only be accommodated in relatively spacious tunnels and at long station platforms. The stresses due to the severity of the service and the weight of the electric apparatus and accessories necessarily carried on the train, are so great that the aggregate weight of the rolling stock rarely averages less than 1,000lb. per seat,* and for more severe services is much higher. Consequently the permanent way has to be of a very substantial nature, and such locations must, notwithstanding the expense, be acquired for the railway, so as to eliminate all possibility that neighbouring property shall be affected by the vibration resulting from the periodic passing of heavy rolling loads.

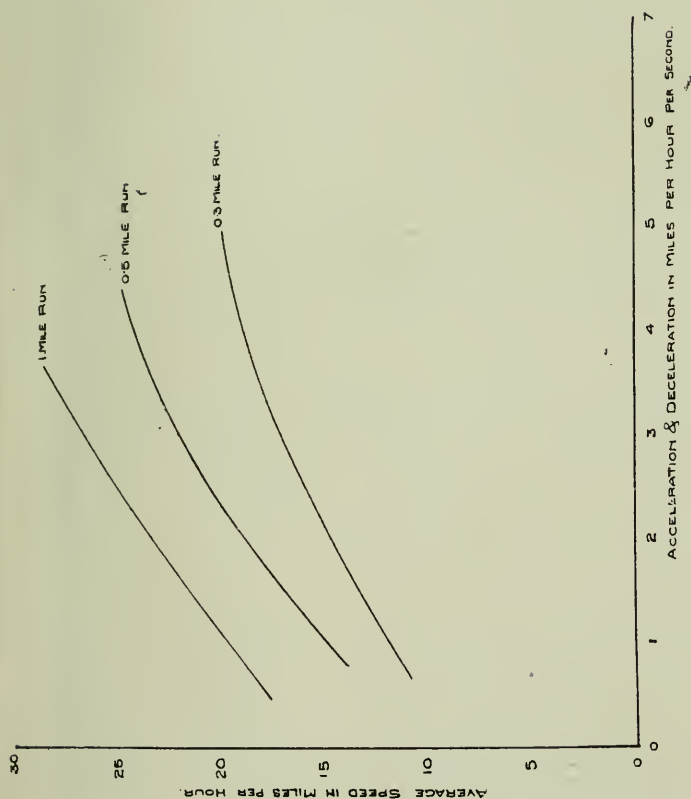
ACCELERATION.

The following investigations of the capabilities of electric traction to meet the requirements of the problem will reveal further very serious results directly traceable to what is obviously at this stage the chief characteristic of the train system, viz. :—“Intermittency.” With the present electric train service in London, the acceleration employed is between 0·8 and 1·4 m.h.s. and for illustrative purposes an acceleration of 1 m.h.s. may be taken as sufficiently typical.

Were it expedient to employ a higher acceleration, there would be no occasion to have recourse to a crest speed so greatly in excess of the average speed. But the inherent (or at any rate the commercially-imposed) limitations of rheostatic and series-parallel control, do not permit of such smooth and carefully graded rate of change of acceleration that a higher average acceleration would be tolerable to passengers. Moreover higher

* As typical instances of the weight of electric trains per seat provided, may be given :—

6-coach train C.L.R.	820lb. per seat.
3-coach train Piccadilly Tube Rly.	900lb. „
3-coach train Heysham Branch of Midland Rly.	940lb. „
4-coach train Southport section of L. & Y. Rly.	1200lb. „
3-coach train L.B.S.C's. South London Elevated	1710lb. „



RATES OF SPEED CHANGE NECESSARY FOR VARIOUS RUNS & SPEEDS

FIG. 4.

acceleration would necessitate increased strength and weight of rolling stock, and would impose on the motors and on the rest of the electrical equipment of the train, also on the transmission line, on the sub-stations and even on the generating station, peaks of loads which can only be provided at a higher average cost per kilowatt-hour than is necessary for the more uniform load, incident to the present acceleration of say 1 to 1.4 m.h.s. The curves in Fig. 4 show the dependence of the average speed upon the acceleration (the braking deceleration being taken in all cases as 1.5 m.h.s.) for various distances between stops as it actually works out for steam trains (which rarely employ accelerations of over 0.4 m.h.s.) and for electric trains with their higher accelerations. These curves show that for runs of a quarter of a mile between stops, trains operated by steam locomotives could not commercially be employed for a service with a schedule speed of over 9 m.h. ; and that a service of electric trains (20 sec. stops) could provide a schedule speed of only about 12 m.h. Even this speed could, with electric trains, be achieved only (as will be shown hereafter), at an inordinate cost and (owing to the necessity of preserving a reasonable distance between successive trains), would not permit of passing more than some 30 trains per hr. as against the limit of 40 trains per hr. for half mile runs.

It is chiefly the ability to provide high acceleration that has led to the adoption of electric methods of operating railways. With the boiler capacity of a large power station behind it, an electric train can be operated at practically any acceleration consistent with the comfort of passengers. Why is it then that in view of the great increase in schedule speed consequent upon the use of very high accelerations, the prevailing practice on electric railways is to operate with accelerations of only say 1 to 1.4 m.h.s. and less? While an acceleration of 1 m.h.s. is high as compared with steam-locomotive practice, it is far lower than could be accomplished with electrical methods, so far as relates to the power which could be developed by the motors.

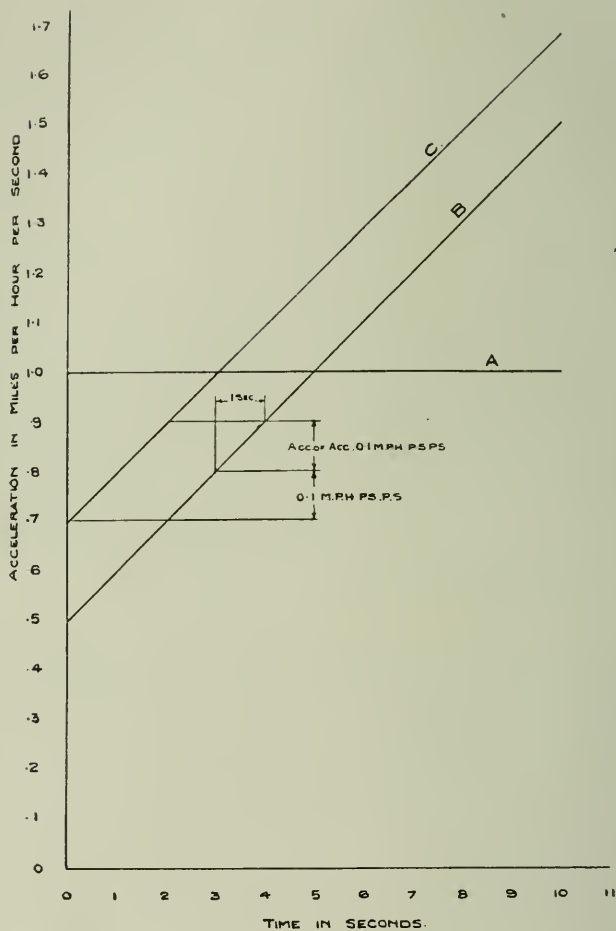
In the first place, high accelerations involve high peak loads and consequent high cost of electrical equipment on the train, high cost of conducting system, and high cost of sub-stations. Secondly, high accelerations mean high tractive efforts and great mechanical strength of trucks, a substantially constructed permanent way, and relatively frequent renewals of rails. Thirdly (and chiefly) out of consideration for passengers, high accelerations can only be employed when carefully graded : *i.e.* consideration has to be given to the acceleration of the acceleration. This important matter has been discussed by Steinmetz (See Proc. Am. Inst. Electrical Engrs., June 19th, 1902, p. 1013) as follows :—

“ It is interesting also to see what refinement the theory gradually develops. The problem was once merely to take a man from one place and put him down in another place, to transport him from a distance. Now you cannot do this instantly, it takes time: it would be rather uncomfortable to do it instantly: consequently we have the speed question. Experience shows that it would be uncomfortable to go at a uniform speed; to start at one place at full speed and stop at another while at full speed; consequently we have to consider acceleration; there is one other feature brought out in Messrs. Arnold and Potter's paper; still further refining the matter, we must not start acceleration constantly. In acceleration we have a second differential co-efficient of the distance; we must not do that instantly, but gradually increase acceleration to full acceleration then gradually decrease it again. Then we have to begin to consider the third differential equation of a distance, to get a maximum speed with the minimum discomfort to the passenger. I look forward to the time when we shall have to consider the fourth and fifth differential. *Without joking, it shows how important these things are, because, if by gradually increasing the acceleration we can run at an acceleration of three miles per hour per second, in rapid transit at a very high speed,—with very frequent stops, it may be the deciding feature of success between the possibility of carrying out the proposition, or the impossibility of carrying it out.*”

GRADUATED ACCELERATION.

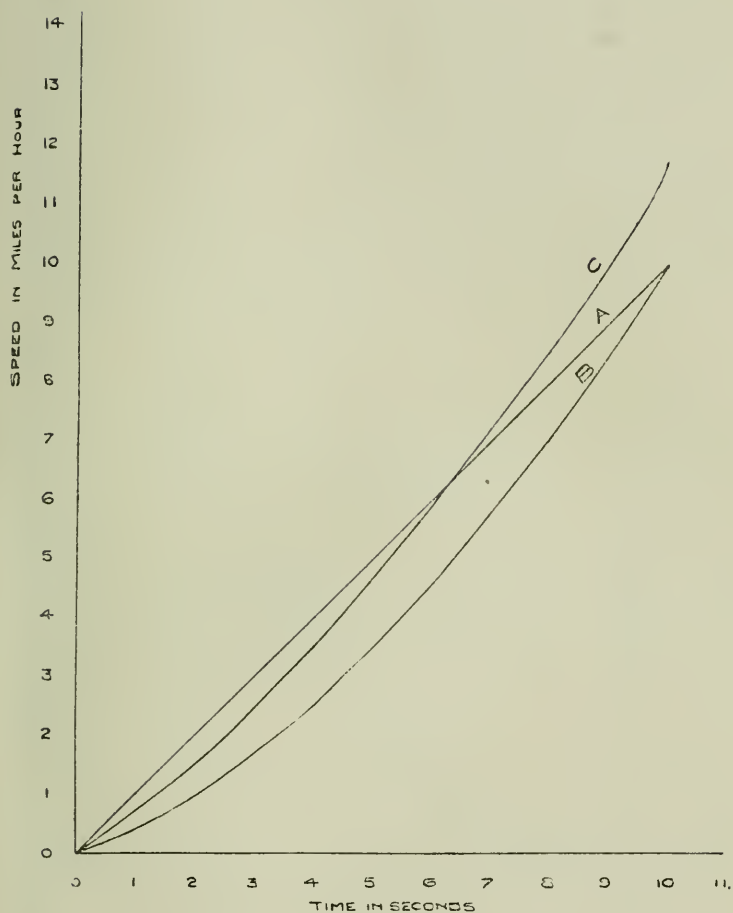
In the above words Steinmetz has touched upon a point of very great interest and importance. Light is thrown upon it by a consideration of Figs. 5, 6, 7. In these figures, cases A, B, and C are studied. In the case of “ A,” a train is started with an acceleration of 1 m.h.s. and the acceleration is maintained constant for 10 seconds, the speed at the end of the 10 seconds thus being 10 m.h. In case “ B ” the mean acceleration for the first 10 seconds is 1 m.h.s., but it is uniformly increased from an initial acceleration of 0·5 m.h.s. until at the end of 10 seconds, the acceleration is 1·5 m.h.s. Thus in 10 seconds the acceleration is accelerated from 0·5 m.h.s. to 1·5 m.h.s. and we may say that the acceleration of the acceleration is $\left(\frac{1\cdot5 - 0\cdot5}{10} = \right) 0\cdot1$ m.h.s.s.

We can go further and consider cases where the acceleration of the acceleration is in its turn varied, but let us first take the simple case where the acceleration of the acceleration is constant. At first glance it may be thought that the use of the acceleration shown by curve “ B ” in Fig. 5 would by the end



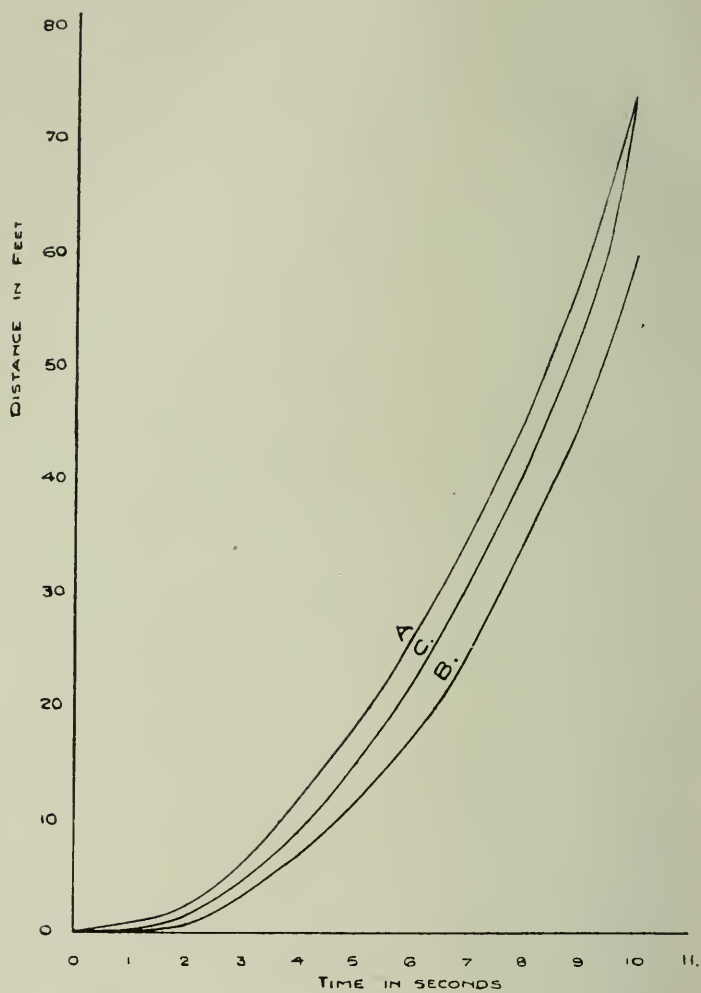
ACCELERATION TIME CURVES.

FIG 5



SPEED. TIME CURVES.

FIG 6



DISTANCE TIME CURVES

FIG. 7

of ten seconds leave the train at the same point, and running at the same speed, as when it is accelerated in accordance with curve "A" since in both cases the mean acceleration is 1 m.h.s. At the end of 10 seconds the speed will, indeed, be 10 m.h. in both cases, but it will be seen by examining the curves "A" and "B" of Fig. 6 that the mean speed is lower in case "B." Consequently the distance traversed is less for case "B," than for case "A" as is confirmed in Fig. 7 where it is seen that in case "B" the train only traverses 60ft. in the first ten seconds as against 73ft. in case "A." A third acceleration curve is shown in Fig. 5 and is designated "C." For case "C" the initial acceleration is 0.69 m.h.s. The acceleration of the acceleration is again 0.1 m.h.s.s., and consequently at the end of ten seconds the acceleration is $(0.69 + [10 \times 0.1] =) 1.69$ m.h.s.

In case "C" the speed at the end of ten seconds is

$$\left(\frac{10 [1.69 + 0.69]}{2} = \right) 11.9 \text{ m.h.}$$

The mean speed for the ten seconds is 5 m.h. just as for case "A," and consequently at the end of ten seconds the train will, as in the case "A," have traversed 73ft.

The following table brings together the data of these three cases :—

Designation	..	..	..	..	"A"	"B"	"C"
Time considered (secs.)	..	..	..	..	10	10	10
Initial acceleration (m.h.s.)	..	..	..	..	1.0	0.50	0.69
Acceleration of the acceleration (m.h.s.s.)	..	..	..	..	0	0.10	0.10
Final acceleration (m.h.s.)	..	..	..	..	1.0	1.50	1.69
Mean acceleration (m.h.s.)	..	..	..	..	1.0	1.0	1.19
Speed at the end of ten seconds (m.h.)	..	..	..	..	10	10	11.9
Mean speed (m.h.)	..	..	..	..	5	4.1	5.0
Distance traversed in 10 secs. (feet)	..	..	..	..	73	60	73

The only advantage of case "B" is the low initial acceleration, and the consequent less discomfort to passengers. At the end of ten secs. case "B" has the disadvantage as compared with case "A" of having traversed only 60ft. as against 73ft. As compared with case "C," it has the disadvantage that at the end of ten seconds its speed is only 10 m.h. while for case "C" it is 11.9 m.h. Case "C" is superior to the others in that while the initial acceleration is distinctly moderate, the final acceleration (1.69 m.h.s.) is acquired with the low acceleration of the acceleration of 0.1 m.h.s.s., and hence without discomfort to the passengers. This results in giving case "C" the advantage of a speed of 11.9 m.h. at the end of ten secs., and the further advantage of its having travelled 73ft. In the practical operation of electric trains, the acceleration, after the initial period, is gradually decreased, but for the further purpose of explaining the advantage of working in the direction of case

"C," let us examine the distance which would be traversed in the following 20 secs., were there no further increment in speed. The results are as follows :—

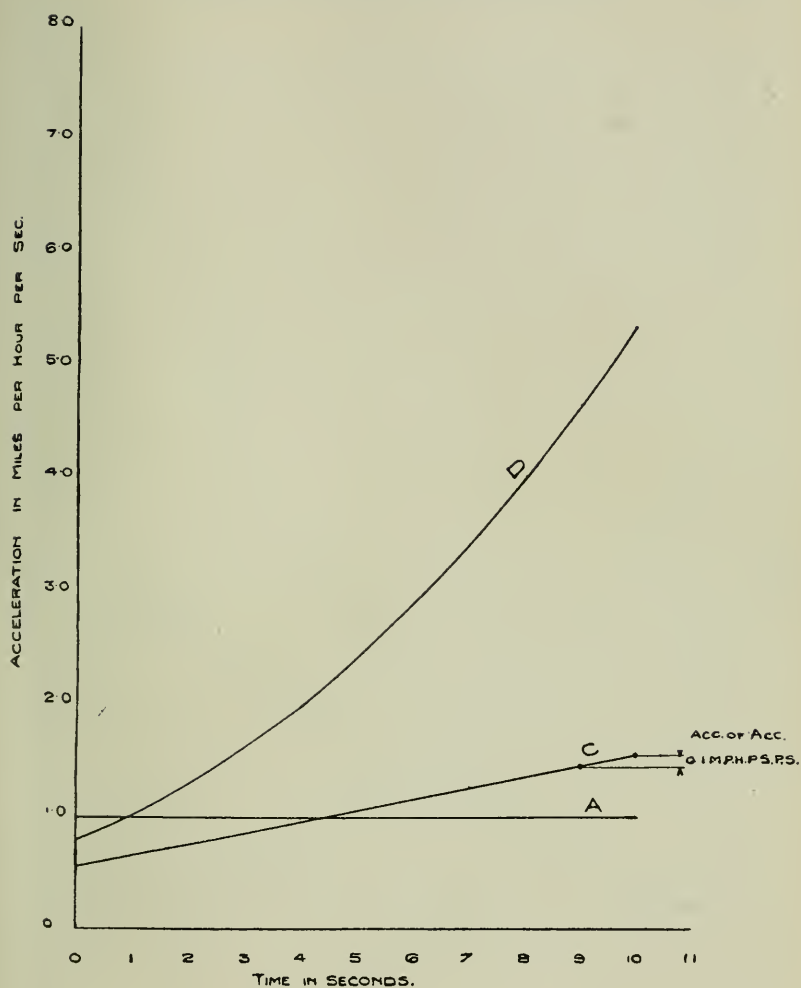
Designation	"A"	"B"	"C"
Distance traversed in first 10 secs. (feet)	73	60	73
Speed (m.h.)	10.0	10.0	11.9
Distance traversed in following 20 secs. (ft.)	292	292	348
Total distance from start (<i>i.e.</i> during 30 secs.) feet	365	352	421
Mean speed for first 30 secs. from start (m.h.)	8.3	8.0	9.5

Leaving case "B" out of consideration (in view of its distinct inferiority) we may contrast case "A," which is representative of present practice with electric trains, with case "C." Case "A" will occasion more discomfort to passengers, due to the higher and sudden initial acceleration, than would be occasioned by case "C." Nevertheless the results achieved as regards the quick attainment of a high speed are inferior to those which would be attained with case "C." But case "C" does not by any means represent the limit consistent with comfort to passengers. It has been demonstrated that passengers find no too great inconvenience to be associated with an initial acceleration of 1.0 m.h.s., or even 1.5 m.h.s.,* but let us take the initial acceleration as only 0.8 m.h.s. thus reserving a large margin and adopting a high standard as regards smoothness of initial starting and speeding up. Furthermore, let the initial acceleration of the acceleration be 0.2 m.h.s.s. but instead of maintaining a constant acceleration of the acceleration let us adopt 0.05 m.h.s.s.s. as the acceleration of the acceleration of the acceleration. Thus we have :—

Initial acceleration	0.8 m.h.s.
Initial acceleration of the acceleration	0.2 m.h.s.s.
Constant acceleration of the acceleration of the acceleration	0.05 m.h.s.s.s.

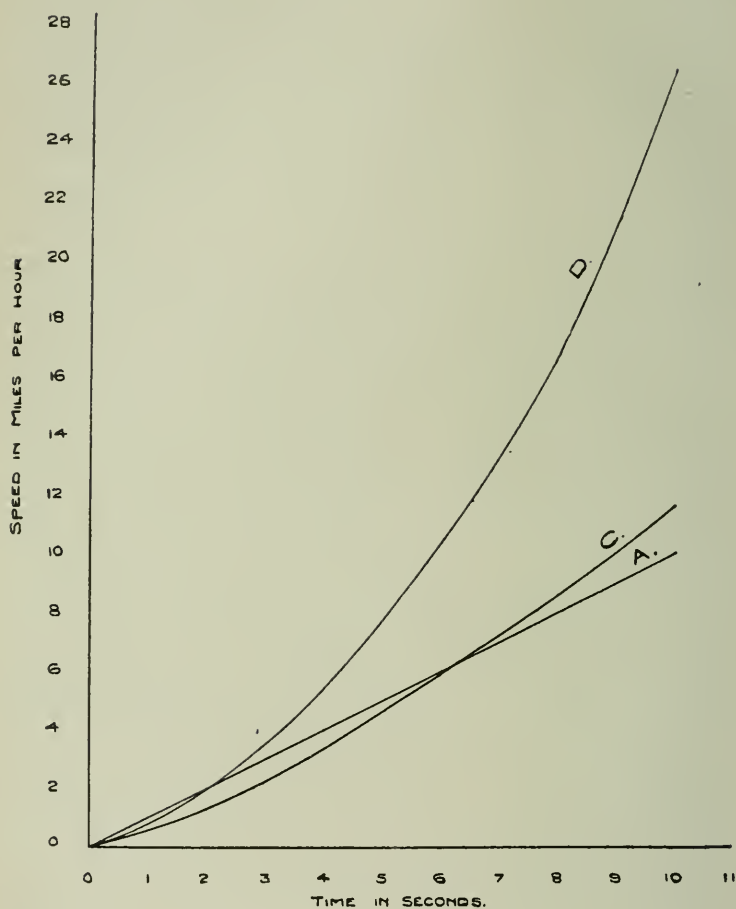
For this plan of operation the acceleration for the first ten seconds is plotted in curve "D" of Fig. 8 where are also represented curves "A" and "C" of Fig. 5. The advantages of case "D" would be still further apparent if the data be worked out for the second 10 secs. as already done for cases A, B, and C. In Figs. 9 and 10 are shown the corresponding

* On lightly loaded trains on the New York Subway and on the Metropolitan Elevated Railway in Chicago the average of a large number of observations indicated that the acceleration is usually of the order of 1.4 m.h.s. (Arnold, pp. 13 and 14 of Report No. 4). On the New York Subway the acceleration during braking is now about 1.5 m.h.s. Dalby in his paper before the British Association (Sept., 1910) states :—"An acceleration of 30 m.h. in 30 seconds is considerably below what may be applied to a passenger without fear of complaint."



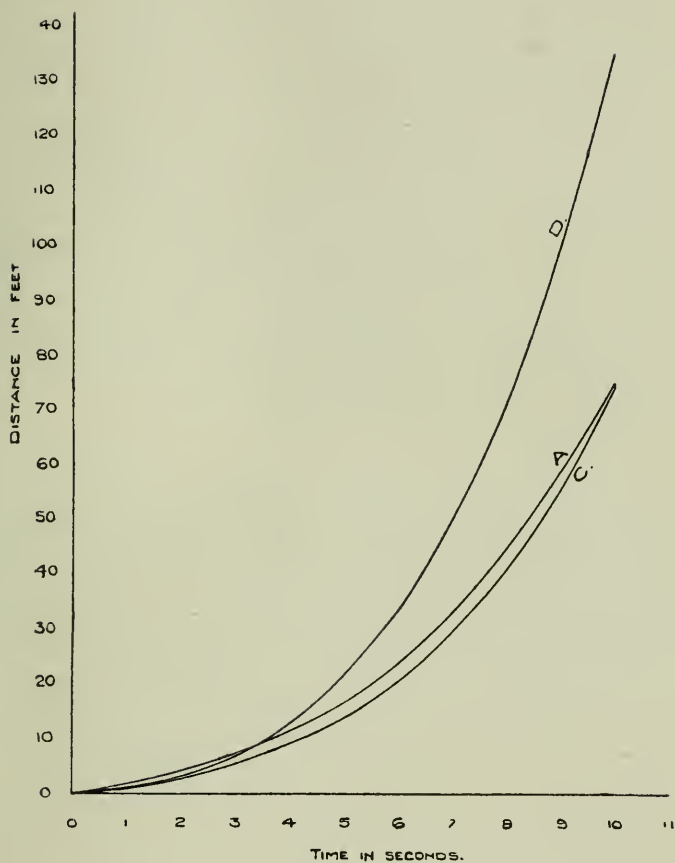
ACCELERATION TIME CURVES

FIG. 8.



SPEED TIME CURVES

FIG. 9.



DISTANCE TIME CURVES

FIG. 10.

speed-time and distance-time curves. The reasons which have already been adduced as limiting in practice the average acceleration of electrically operated trains to between 0·8 m.h.s. and some 1·4 m.h.s. might in various instances be insufficient in view of the great importance of high schedule speeds with frequent stops. But at present there is a more cogent reason for these limitations and this reason will now be discussed:—

If means were available whereby a train could be brought up to speed in strict accordance with the acceleration time curve “D” of Fig. 8, in which the mean acceleration for the first ten secs. is 2·6 m.h.s., it is highly probable that this would be equally or even more consistent with the comfort of passengers than the present practice of electric trains, which employ for the first ten seconds an average acceleration of the order of only about 1 m.h.s. The difficulty consists in obtaining by electrical methods any approach to the refinements as regards the application of the acceleration, presented by curve “D” of Fig. 8. The conditions corresponding to present practice are in fact, far worse than is generally realised.

ACCELERATION ON THE “MOTOR CHARACTERISTIC.”

At a certain stage in the acceleration of an electric train, the external resistances are all cut out (or in single phase traction, the last tap from the transformer is reached) and during the remainder of the acceleration period, the acceleration decreases smoothly in accordance with a curve depending on the design of the motor, and known as the “motor characteristic.” The time at which this stage of the acceleration is reached varies with the service, but consider a case where acceleration on the motor characteristic is reached at the end of the tenth second from the moment of starting the train, and let us further assume, that up to this point, the acceleration has been uniform and equal to 1 m.h.s. Consequently at the commencement of the acceleration on the motor curve, the train’s speed is 10 m.h. and the train will have travelled a distance of 73ft. In Fig. 11 is shown a representative acceleration time curve for the following 20 seconds.

An analysis of Fig. 11 will show that the motor characteristic displays a varying deceleration of the acceleration. All experienced “straphangers” can testify to the smoothness of operation on the motor characteristic. They will have observed that the first few seconds of jerky starting is succeeded by an all-too-short period of smooth acceleration. This smooth acceleration is that on the “motor characteristic.” Thus the natural properties of the motor provide much that can be desired as regards smooth acceleration. All the disagreeable features of the accelerating stage are confined to the first few

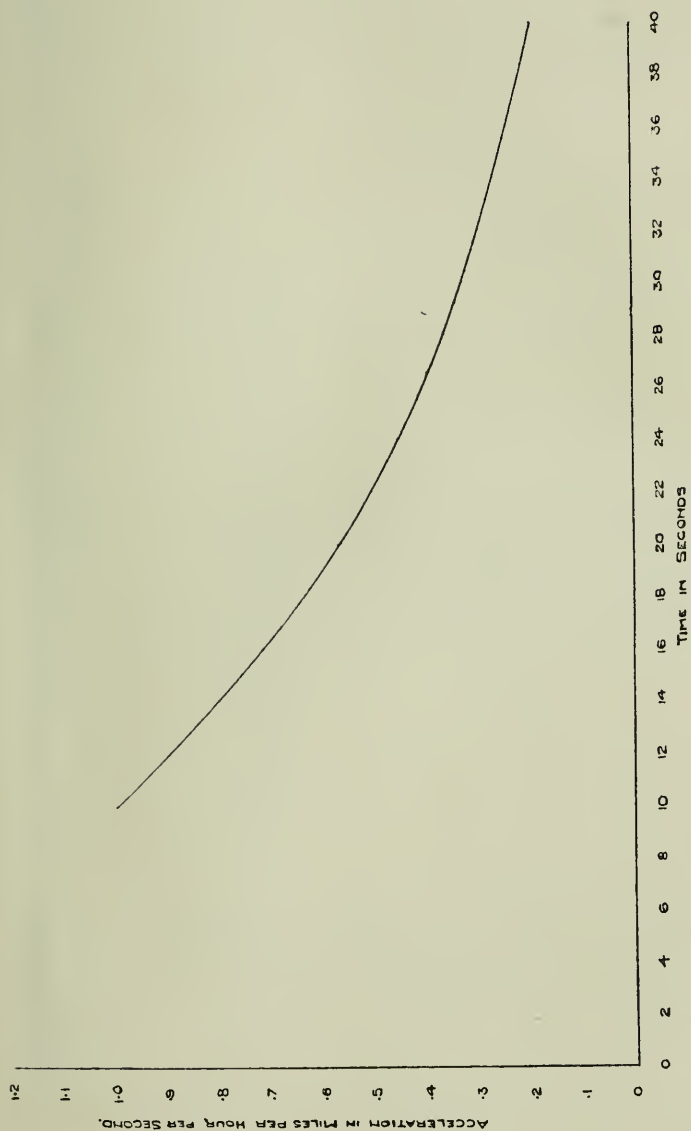
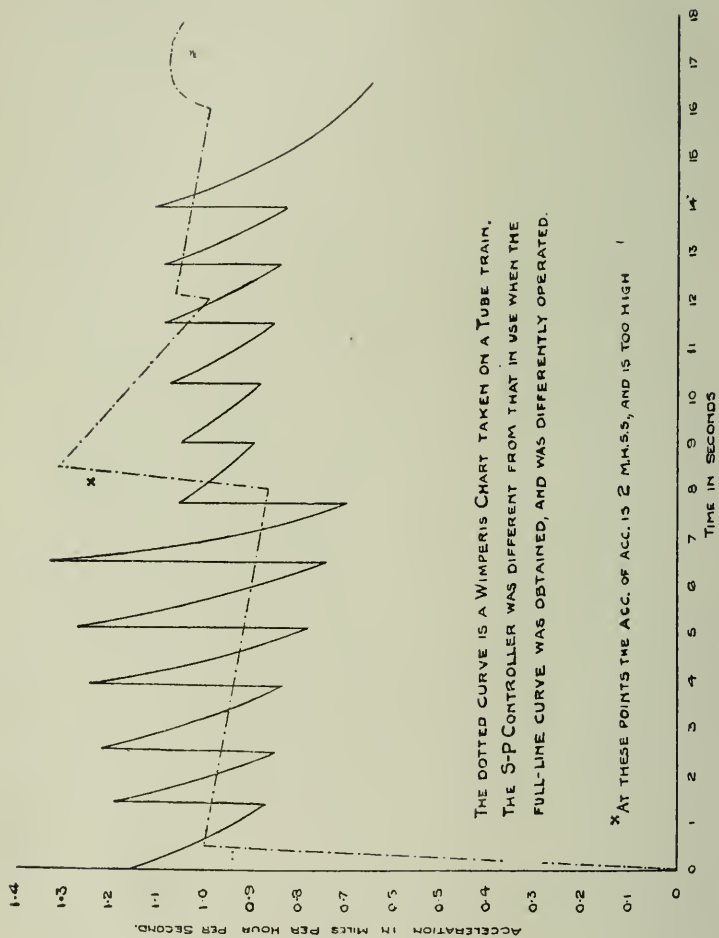


FIG. 11

ACCELERATION ON THE MOTOR CHARACTERISTIC CURVE



THE DOTTED CURVE IS A WIMPERIS CHART TAKEN ON A TUBE TRAIN.
THE S-P CONTROLLER WAS DIFFERENT FROM THAT IN USE WHEN THE
FULL-LINE CURVE WAS OBTAINED, AND WAS DIFFERENTLY OPERATED.

CHARACTERISTIC CURVES WITH SERIES-PARALLEL CONTROL

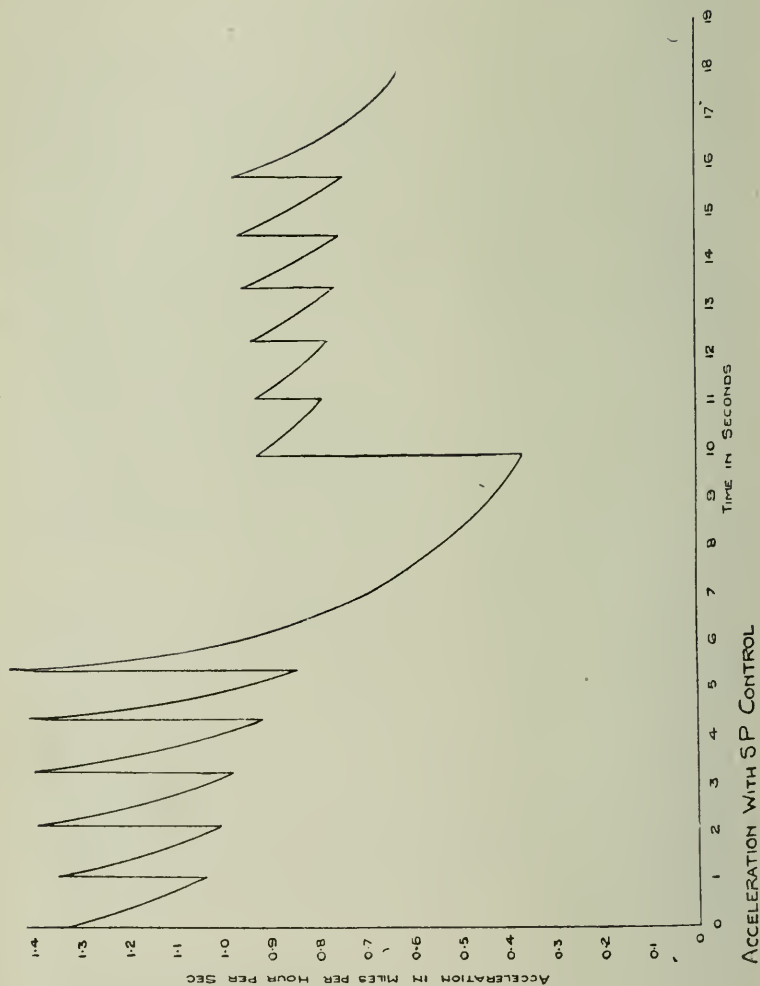
seconds, corresponding to rheostatic acceleration, or "notching" as it is sometimes called. If it were commercially expedient to employ an infinite number of controller points, then the initial stage of "notching" acceleration could, with sufficient manual skill on the part of the driver, be made as smooth as the following stage of acceleration on the "motor characteristic." In that case it would be practicable to resort to much higher mean accelerations than are at present expedient.

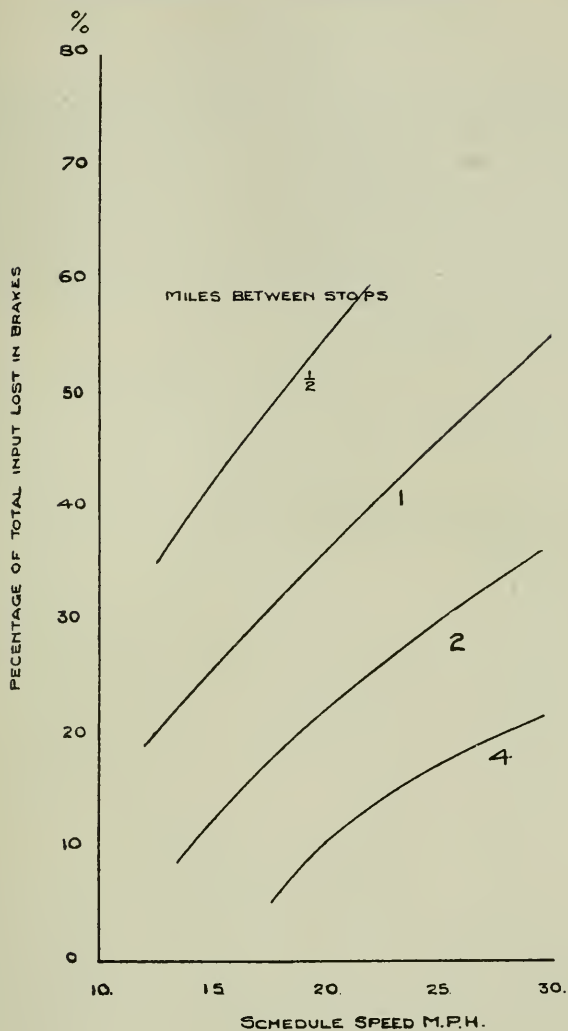
SAW-TOOTH ACCELERATION.

The curves in Figs. 12 and 13 are representative of the variations in acceleration during "notching." It will be seen that at each of the notches, the acceleration is abruptly varied from 20 to 50%.* At these points the acceleration of the acceleration approaches infinity. If the passengers are observed, it will be seen that they all nod in unison at each notch. Since this is the result of a 20 to 50 % variation when the mean acceleration is 1 m.h.s. it is obvious that it is the *abrupt* changes in the rate of acceleration which incommode passengers. Much higher accelerations will occasion no inconvenience to the passengers if only the changes are imparted in accordance with such curves as that in Figs. 11 and 8 "D." Also as regards braking, the very best equipments are never immune from the liability of producing, on occasions, exceedingly uncomfortable decelerations; such, for instance, as so peremptorily expedite one's progress to the end of the car on leaving one's seat when about to alight; but if the deceleration of the deceleration could be brought under control, much higher mean decelerations would be accompanied by less discomfort to passengers than the at-present-customary braking deceleration of from 1.5 to 2.5 m.h.s.

The author has dealt somewhat lengthily with the question of acceleration in order to indicate a very hopeful field for research and invention, with the object of improving electric train operation, and so improving the system as will enable it better to approach the ideal acceleration set forth in curve "D" Fig. 8. Retardation of the same nature is also desirable. It is obvious that electric traction would obtain greatly superior results were it possible to apply the same degree of refinement to braking; and still further advantages if it were practicable to return energy to the line during the period of retardation instead of wasting the large amount now dissipated at the brake blocks—a detrimental feature of electric traction which should be obviated.

* Refer to Wimperis' Accelerometer records of electric train performances. The dotted curve on Fig. 12 shews a record taken on a London sub-surface railway.





BRAKE LOSSES.

Quite aside from the discomfort to passengers which is a practically inseparable attribute of the present system of braking railway trains, the waste of energy as heat at the brake blocks is enormous, especially for short runs at high speeds. This is very apparent from Fig. 14.* From this diagram we see that in the present electric train system, a schedule speed of 30 m.h. with one stop per mile involves the waste of over half the input of energy in heat at the brake shoes. Values for various other cases are given in the following table, and Figs. 15 and 16* are strikingly illustrative.

Schedule speed	Length of Run from Start to Stop.	
	0·5 mile.	1 mile.
	Brake loss	Brake loss
15·0 m.h.	40% of input	24% of input.
17·5 „ ..	48% „	30% „
20·0 „ ..	53% „	35% „
22·5 „ ..	59% „	40% „
25·0 „ ..	—	45% „

ENERGY CONSUMPTION.

It has been stated† that 1,000 lb. is a representative value of the aggregate weight of rolling stock per seat provided for urban and suburban electric trains. This large weight would be of minor consequence were it simply a matter of the correspondingly large capital cost of the rolling stock, which for electric trains is roughly about £74 per ton, or £33 per seat. But in the operation of a frequent-stop service by means of electric trains, the bulk of the electricity required is for the purpose of providing the momentum corresponding to the crest speed. From Fig. 17* it will be seen that for a service with frequent stops, the attainment of satisfactory schedule speeds is dependent upon resorting to crest speeds greater by 50% and more than the schedule speeds. Thus for a 16

* By kind permission of the publishers of "Electric Trains," by Hobart.

† See footnote on p. 130.

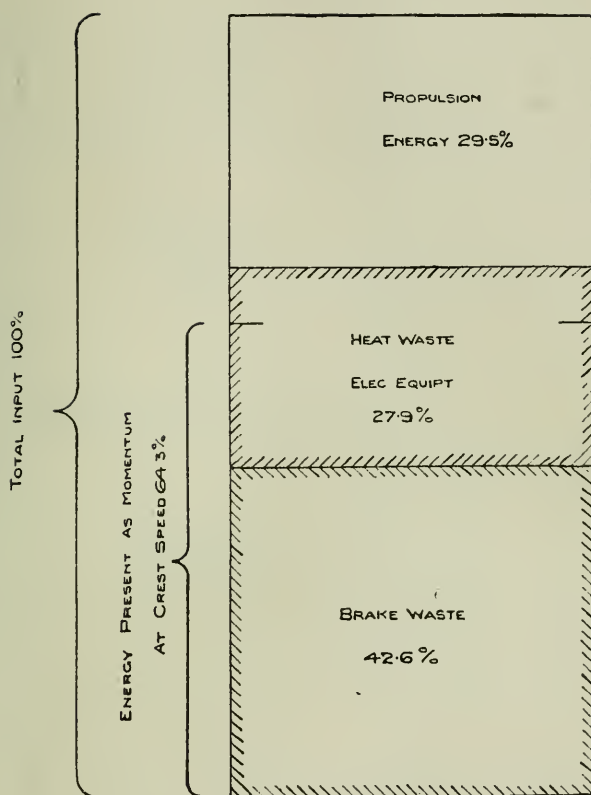


DIAGRAM SHEWING ALLOCATION OF ENERGY INPUT FOR A SERVICE WITH AVERAGE DISTANCE OF 0.30 MILES FROM START TO STOP & SCHEDULE SPEED OF 12.7 M.P.H

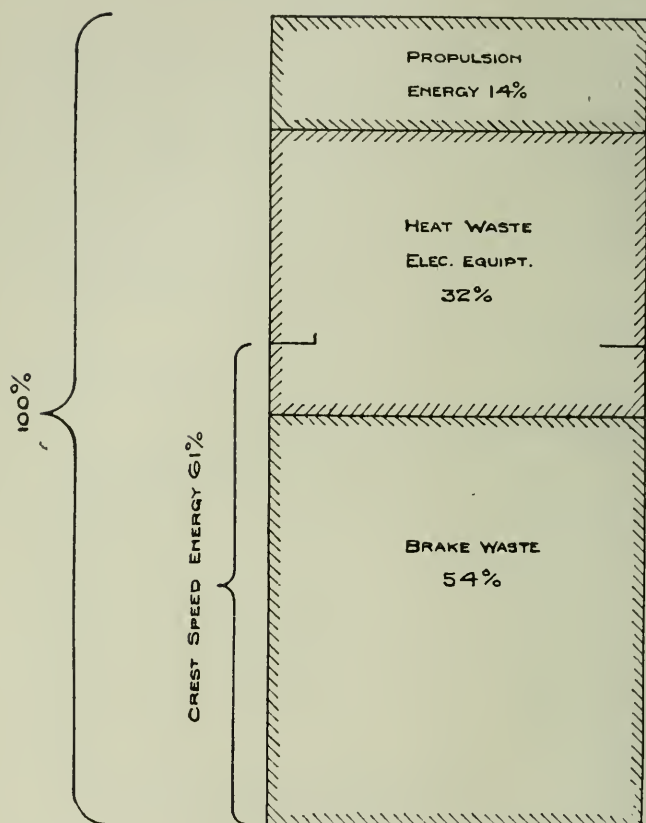
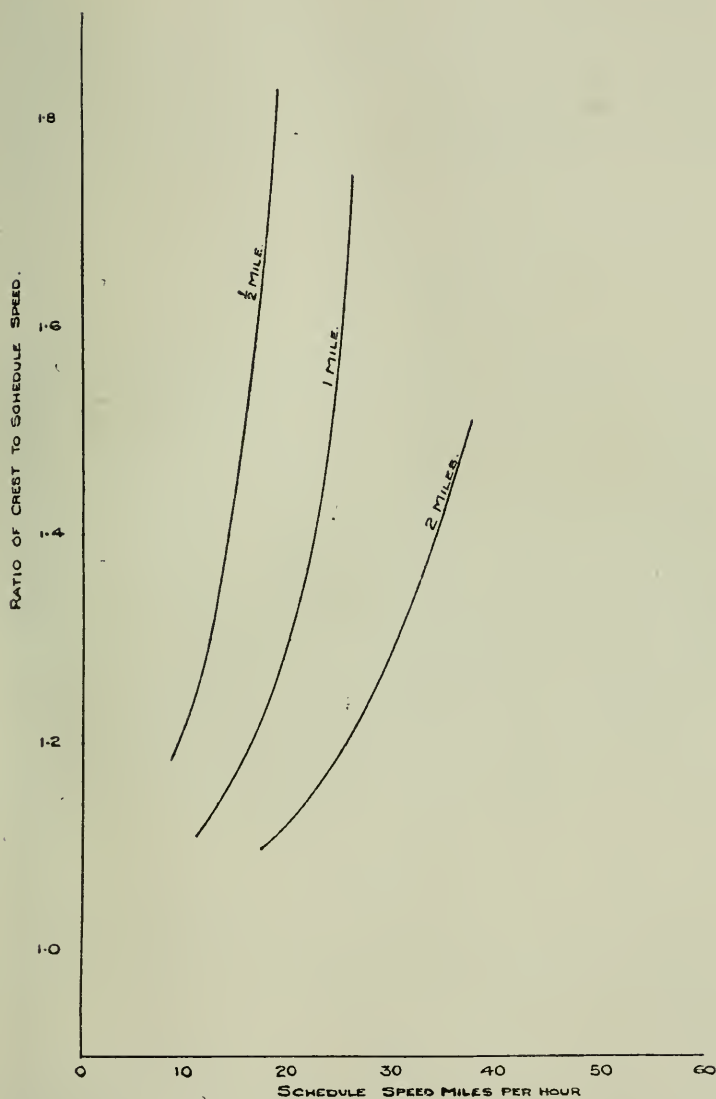


DIAGRAM SHEWING ALLOTMENT OF TOTAL INPUT TO 100 TON
 TRAIN RUNNING AT SCHEDULE SPEED 30 M.P.H. DISTANCE BETWEEN
 STATIONS BEING 1 MILE.



RATIO OF CREST TO SCHEDULE SPEED FOR VARIOUS RUNS WITH ACCELERATION OF 1 M.P.H. PER SEC. & BRAKING 1.5 M.P.H. PER SEC (ASSUMING FRICTIONLESS RUN)

NECESSARY CREST SPEED

FIG. 17.

m.h.-2-stops-per-mile service, the crest speed is 60% higher than the schedule speed. In view of the fact that the kinetic energy is proportional to the square of the crest speed, and considering the great weight of rolling stock per seat, it is obvious that this is a serious matter. For a 16 m.h.-2-stops-per-mile service with 20-second stops, the crest speed is quite ($16 \times 1.6 =$) 25.6 m.h. At a speed of 25.6 m.h. the kinetic energy for each run is ($0.0303 \times [25.6]^2 =$) 19.8 w.hr. per ton, and when there are two stops per mile, it is $\left(\frac{19.8}{0.5} =\right)$ 39.6 w.hr. per ton-mile. The energy expended to overcome the train resistance in such a case is only about $\left(\frac{7 \times 1609}{367} =\right)$ 30.6 w.hr. per ton mile.

This train friction energy is divided into two portions. The first is the friction energy for the distance traversed, from the moment of starting up to the instant when the electricity is cut off, and the second is the friction energy for the distance traversed from the instant of cut off until the train is at rest again. The percentage belonging to each of these two stages varies with the service, but it will not introduce appreciable error to take the two portions as equal, and this will permit of abbreviating the calculation. Thus the friction energy of 30.6 w.hr. per ton-mile consists of 15.3 w.hr. per ton-mile for the first period, during which the friction energy is furnished directly from the electricity supply, and 15.3 w.hr. per ton-mile for the second period during which the friction energy is recovered from the energy of momentum. The wasted portion of the kinetic energy is consequently, ($39.6 - 15.3 =$) 24.3 w.hr. per ton-mile.

The efficiency of the electrical equipment on the train may be taken as just about 70%. Thus for the service in question the input to the train is $\left(\frac{39.6 + 15.3}{0.7} =\right)$ $\frac{54.9}{0.7} = 78.5$ w.hr. per ton-mile, or (at 1,000lb. per seat) $\left(\frac{1000}{2240} \times 78.5 =\right)$ 35 w.hr. per seat-mile.

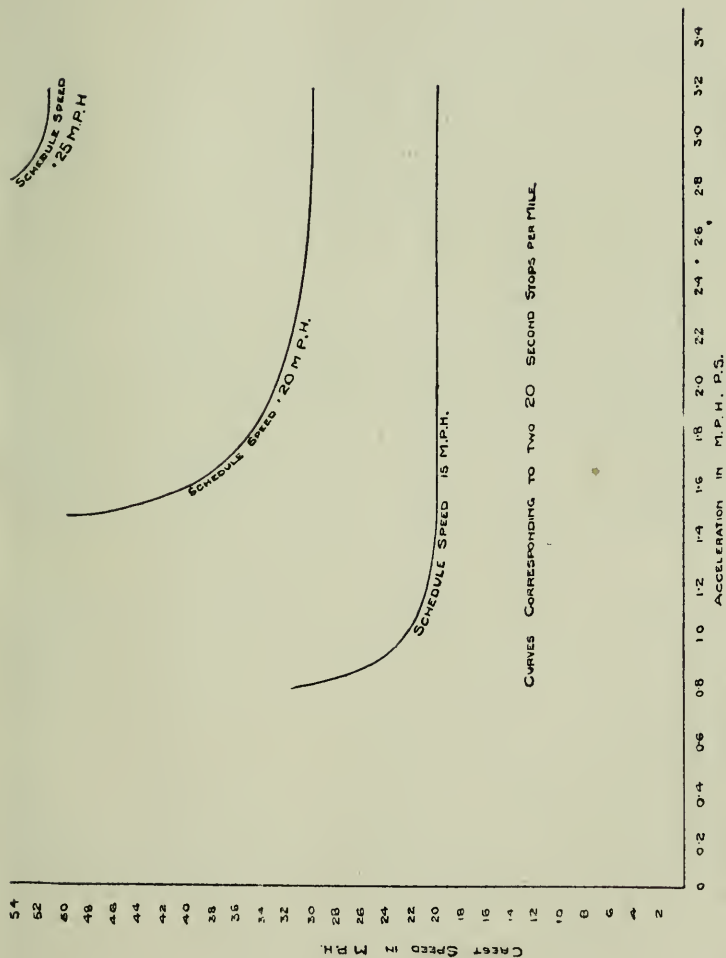
If the train had been devoid of momentum*, and if consequently it had been simply a matter of overcoming friction, the energy consumption would have been :—

$\left(\frac{30.6}{0.7} =\right)$ 43.7 w.hr. per ton-mile or 19.6 w.hr. per 1000lb. seat-mile.

In view of these basic circumstances, it is obviously of importance to maintain the required schedule speed with as

* Hobart, in his book, "Electric Trains" published in 1910 directs attention (see pp. 23, 24 and 25) to the advantages and possibilities of the well known "moving platform" system which is one that is devoid of momentum.

FIG. N° 18.



CURVES SHOWING CREST SPEEDS NECESSARY FOR VARIOUS SCHEDULE SPEEDS WITH DIFFERENT ACCELERATIONS
, FOR 2 STOP PER MILE SERVICE

low a crest speed as practicable. A very considerable measure of advantage in this direction may be obtained by resorting to high acceleration. In Fig. 18 are given several curves indicating for several schedule speeds, the crest speed necessary with various accelerations for a 2-stop-per-mile service. It is seen from the curve for a schedule speed of 15 m.h. that while with an acceleration of only 0.9 m.h.s. the crest speed must be about 25 m.h. (or 66% greater than the schedule speed) an acceleration of 1.5 m.h.s. reduces the required crest speed to only 20 m.h. (or only 33% greater than the schedule speed).

Returning to our 16 m.h. 2-stop-per-mile example for which, with the accelerations customary with electric trains, the crest speed is 25.6 m.h. (or 60% greater than the schedule speed) let us examine the consequences of employing such an acceleration that the crest speed need be only 21 m.h. (31% above the schedule speed). By interpolating amongst the curves in Fig. 18 we find that the required acceleration must be 3 or 4 m.h.s. The energy for momentum required to be provided will be reduced to $\left(\frac{21^2}{25.6^2} \times 39.6 = \right) 26.6$ w.hr. per ton-mile.

The energy required to be supplied for propelling the train against friction will be reduced, firstly, because the journey will be made at a lower crest speed, and secondly, because with the higher acceleration, the point of cut-off is reached at an earlier point of the route. Without taking the time for precise calculations, let us take the friction up to the point of cut-off at 14 w.hr. per ton-mile as against the former figure of 15.3 w.hr. per ton-mile. The total input to the train works out at

$$\left(\frac{26.6 + 14.0}{0.7} = \right) 58 \text{ w.hr. per ton-mile.}$$

as against the former figure of 78.5 w.hr. per ton-mile, a reduction of 26.2%. But in view of the crude nature of acceleration as at present attainable with, and applied on, electric trains, so high an acceleration as 3 or 4 m.h.s. would occasion too great discomfort to passengers, and furthermore, were we to analyse the proposition from the standpoint of cost, we should find it altogether impracticable.

Let us however, make the further supposition that the weight of the rolling stock per seat provided could, by more scientific design, be halved, then the consumption would come

down to $\left(\frac{58}{78.5} \times \frac{1}{2} \times 19.6 = \right) 7.25$ w.hr. per seat-mile,

or only $\left(\frac{7.25}{19.6} \times 100 = \right) 37\%$ of the seat mile consumption corresponding to present electric train methods as applied to a 2-stop-per-mile-16-mile-per-hour service.

It is desirable at this point to emphasize that *any alternative to the electric train method of handling passengers could well have the attribute of, (i.) low weight of rolling stock per seat provided, (ii.) such finer regulation of the acceleration and deceleration as to permit employing mean accelerations and decelerations several times as great as those customary with electric trains, (iii.) regeneration during deceleration.**

THE COST OF THE ELECTRIC TRAIN SYSTEM.†

In arriving at sufficiently representative figures for the cost of electric traction, we may follow the simple, though efficient method put forward by Hobart, as exemplified in his paper "The cost of Electrically Propelled Suburban Trains," Proc. Inst. Mech. Engrs., July 29th, 1910.

For electric trains the capital cost of the rolling stock is shown by Hobart to work out at from £72 to £92 per ton, according to the system employed and the service provided. In order that in the comparisons any points of doubt shall be dealt with in such a way as to avoid any unfairness to the electric train system, let us take the cost of the rolling stock as £74 per ton, although so low a cost is exceptional, and is only attained for moderate services as regards speed and frequency of stops. Reverting to the earlier figure of 1,000lb. as representative of the weight of the rolling stock per seat provided, and taking the case of a 6-car train providing 300 seats, the weight of such a train works out at $\left(\frac{300 \times 1,000}{2,240} = \right)$ 134 tons.

Let a service of such trains be operated over a 6-mile double track route and let us take two cases. In the first case denoted as Road "A" let there be two stops per mile and in the second case, Road "B," four stops per mile. The first case is typical of the London tube and underground railways and, for a schedule speed of 16 m.h., permits of a rush-hour service of 40 trains per hour in each direction. The 4-stop-per-mile service is hypothetical, and if it were carried out, with 15-sec. stops, it would, for reasons which have already been touched upon in this paper, permit of a schedule speed of only about 12 m.h., and a rush-hour service of say 30 trains per hour in each direction. During the times of light traffic, the trains may in each case, be halved, and operated as three car units. The accumulated experience on lines of this character is that the traffic is so distributed that, taken over the entire 8,760 hours in the year, the average number of seats passing in a given direction per hour, is of the order of one-third of the number during the

* These three and other advantageous features are attained in the Adkins-Lewis continuous system recently put forward by the author. (See Royal Society of Arts paper, Dec. 15th, 1911.)

† The data used are somewhat too favourable to the electric train system as applied and operated in London,

rush-hours.* Consequently at hours of light traffic, not only do the half-length trains suffice, but there is insufficient traffic to justify as many trains per hour as during the rush hours. The maximum seats per hour in each direction are :—

Road "A" $40 \times 300 = 12,000$ seats per hour.

Road "B" $30 \times 300 = 9,000$ " "

The average over the entire 8,760 hours in the year is :—

Road "A" .. $12,000 \times 0.33 \dots = 4,000$ seats per hour.

Road "B" .. $9,000 \times 0.33 \dots = 3,000$ " "

Since the roads each comprise 6 miles of double track and since the schedule speeds are respectively 16 m.h. and 12 m.h., the seat mileage works out at :—

For Road "A" .. $12 \times 4000 \times 8760 = 420$ million seat-miles per annum.

For Road "B" .. $12 \times 3000 \times 8760 = 315$ million seat-miles per annum.

The rolling stock will weigh 1,000lb. (0.445 ton) per seat : thus we have :—

For Road "A" .. $420 \times 10^6 \times 0.445 = 188$ million ton-miles per annum.

For Road "B" .. $315 \times 10^6 \times 0.445 = 140$ million ton-miles per annum.

The next step relates to the estimation of the energy required for such services. In the case of Road "B" with twice as many stations per mile, there would be a better distribution of the passengers (and for this reason less congestion and delays in boarding and leaving trains) were it not for the lesser frequency of the trains (30 per hour for Road "B" against 40 per hour for Road "A"). This lesser frequency will modify the relief of the congestion consequent upon the greater number of stations. For our rough practical comparison of the two roads, it would thus appear most reasonable to take the average duration of the stops at stations at 15 seconds in both cases.

For the conditions of test runs, the consumption energy at the train may be taken as :—

† 66 w.hr. per ton-mile for Road "A" with 16 m.h. and 2 stops per mile.

105 w.hr. per ton-mile for Road "B" with 12 m.h. and 4 stops per mile.

Making in both cases a 30% allowance for the differences between the conditions of test runs and the conditions of actual operation, including allowance for the weight of passengers, the annual consumption of electricity at the trains will be :—

For Road A $\frac{188 \times 10^6 \times 66 \times 1.3}{1000} = 16.1$ million kw.hr. per ann.

For Road B $\frac{140 \times 10^6 \times 105 \times 1.3}{1000} = 19.1$ " " "

* See Addendum A, p. 164.

† See Addendum B, p. 164.

At the outgoing cables from substations these amounts are increased to :—

For Road A—16·5 million kw.hr. per annum.

For Road B—19·5 " " "

The average annual efficiency of the substations will be about 89%. Consequently for the annual input to the substations we shall have—

For Road A : $\frac{16\cdot5}{0\cdot89} = 18\cdot5$ million kw.hr. per annum.

For Road B : $\frac{19\cdot5}{0\cdot89} = 21\cdot9$ " " "

The maximum sustained loads at the substations will occur during the 'rush hour' periods and will amount to :—

For Road A : $\frac{16\cdot5 \times 10^6}{8760 \times 0\cdot33} = 5,650$ kw.

For Road B : $\frac{19\cdot5 \times 10^6}{8760 \times 0\cdot33} = 6,700$ k.w.

The capital outlay for these substations may be approximately taken at : Road A = £40,000. Road B = £44,000.

Let us take the cost of the electrical work between substations and trains at £2,000 per mile of single track or a total of $(12 \times 2,000 =)$ £24,000 for the route in both cases A and B.

We now come to the consideration of the cost of rolling stock. For the services considered, the required amount of rolling stock is a function of the "rush-hour service."

For Road "A" the speed is 16 m.h., and the round trip of 12 miles occupies $\left(\frac{12 \times 60}{16} = \right)$ 45 minutes. Since during the rush hours there are 40 six-car trains per hour, there will be simultaneously required on the route $\left(\frac{45 \times 40}{60} = \right)$ 30 trains.

With 15% reserve, this comes to an aggregate rolling stock of $\left(\frac{30}{0\cdot85} = \right)$ 35·3 or —say—35 trains, or $(35 \times 6 =)$ 210 cars.

In the same way for Road "B," where the speed is 12 m.h. the round trip of 12 miles occupies just 60 minutes. During the rush hours there are 30 six-car trains per hour, consequently 30 trains will be simultaneously required on the route, or again a total rolling stock of 35 trains (or 210 cars). On the basis of £74 per ton, each train will cost $(134 \times 74 =)$ £10,000, or in both cases a total of £350,000 for the rolling stock. Each car, since it has 50 seats, will weigh $(0\cdot445 \times 50 =)$ 22·4 tons on the average.

Each car will have a total mileage per annum of :—

For Road "A" :— $\frac{188 \times 10^6}{22.4 \times 210} = 40,000$ miles per annum.

For Road "B" :— $\frac{140 \times 10^6}{22.4 \times 210} = 30,000$ miles per annum.

The three chief items of capital cost for electrical work and rolling stock for the two cases are given in the following table, and in the last column are given appropriate percentages for the annual outlay for maintenance and renewals.

	Road "A."	Road "B."	% for main- tenance and renewals.
	£	£	
Substations	40,000	44,000	6%
Contact conductors and in- sulators, bonding, feeders	24,000	24,000	6%
Rolling stock	350,000	350,000	10%
Total	£414,000	£418,000	

Maintenance and Renewals.	Road "A."	Road "B."
	£	£
Substations	2,400	2,640
Conductors, etc.	1,440	1,440
Rolling stock	35,000	35,000
Total I.	£38,840	£39,080

The capital outlay for tunnels, running rails, stations, booking offices, sheds, repair shops, signalling system, etc., may be taken at £450,000 per mile for Road "A" with two stations per mile, and at £550,000 per mile for Road "B" with four stations per mile. The maintenance and renewals under these heads may be taken at 1.5 %, making an annual charge of :—

For Road "A" :— $450,000 \times 6 \times 0.015 = £40,500.$
 For Road "B" :— $550,000 \times 6 \times 0.015 = £49,500.$ } Total II.

Thus for maintenance and renewals for the complete undertakings we have :—

	Road "A."	Road "B."
	£	£
I. Of rolling stock & electrical items	38,840	39,080
II. Of tunnels, etc.	40,500	49,500
Total annual outlay for main- tenance and renewals (I. + II.)	£79,340	£88,580

The total capital outlay amounts to—

	Road "A."	Road "B."
	£	£
Rolling stock and electrical items ..	414,000	418,000
Tunnels, etc.	2,700,000	3,300,000
Total Capital Outlay ..	£3,114,000	£3,718,000

Taken at 4% interest on the capital outlay, then for interest, maintenance and renewals, we have :—

	Road "A."	Road "B."
	£	£
I. + II. Maintenance and renewals ..	79,340	88,580
III. Interest at 4%	124,500	148,500
I. + II. + III.	£203,840	£237,080

Amongst the further chief charges is the cost of electricity.* On the reasonable basis of an average of 0.6d. per kw.hr. as delivered to the substations in the form of high tension three-phase electricity, this works out at :—

$$\text{For Road "A" :—} \frac{18.5 \times 10^6 \times 0.6d}{240} = \text{£}46,300.$$

$$\text{For Road "B" :—} \frac{21.9 \times 10^6 \times 0.6d}{240} = \text{£}54,800.$$

Wages for train crews and for platform staff will run to about 4d. per train mile for Road "A," and to say 6d. per train mile for Road "B" making the annual totals shown in the last column of the following table :—

Annual Train Mileage (reduced to equivalent 6-car trains.)	Annual Outlay for Wages for Train Crews and Platform Staff.
Road "A" $\left(\frac{188 \times 10^6}{134} = \right) 1.4 \times 10^6$	$\left(\frac{1.4 \times 10^6 \times 4}{240} \right) = \text{£}23,400.$
Road "B" $\left(\frac{140 \times 10^6}{134} = \right) 1.05 \times 10^6$	$\left(\frac{1.05 \times 10^6 \times 6}{240} \right) = \text{£}26,200$

For booking office staff and lift attendants we may reasonably assign as wages :—

For Road "A" .. £6,000 For Road "B" .. £8,000.

For both cases we may reasonably take :—

Wages of substation staff, signalmen
and of workmen on the line .. £3,000 per annum.

* See Addendum C. p. 164.

Management charges, insurance,
taxes, printing and all other costs
of the undertakings £35,000 per annum.
Bringing together all the above items we have :—

	Total Annual Costs		Per 6-car train-mile	
	Road "A."	Road "B."	Road "A."	Road "B."
	£	£	d.	d.
Interest on capital outlay	124,500	148,500	21·4	34·0
Maintenance and renewals	79,340	88,580	13·6	20·2
Electricity	46,300	54,800	7·9	12·5
Wages of train crews and platform staff	23,400	26,200	4·0	6·0
Wages of lift attendants and booking office staff	6,000	8,000	1·0	1
Wages of sub-station staff, signalmen and workmen on line	3,000	3,000	0·5	0·7
Management charges, insurance, taxes, printing, etc.	35,000	35,000	6·0	8·0

Total annual costs .. £317,540 £364,080

Total per train mile for 6-car trains 54·4 83·2

* The experience on London's tube and underground railways, where the average practice is to employ two stations per mile, and on which the service as regards speed and number of trains per hour, approaches the Road "A" of our example, is that the receipts average only about 0·19d. per seat-mile in favourable cases. For a 6-car, 300-seat train, this would amount to receipts of about $(300 \times 0·19 =)$ 57d. per train mile, thus leaving a small margin of profit over the above ascertained cost of 54·4d. per train mile for Road "A."

No road exists in London with any such conditions as those of Road "B" with four stations per mile, but it could be fairly anticipated that the greater convenience of the more numerous stations would be more than set off by the low speed of 12 miles per hour, which low speed is, with electric trains, an inevitable consequence of the intermittent service with the short distances between stations. Consequently the receipts per train mile would probably be but little greater than 57d., and the undertaking could not possibly be operated profitably, since as above worked out, the total costs come to no less than 83·2d. per train mile. Thus it is fairly evident that one half mile between stations is very near the limit of the commercially practical frequency of stations for an electric train system in

* See Addendum D, p. 164.

London. When with such a system the schedule speed is 16 m.h. a rush-hour service of 12,000 seats per hour in each direction is provided, and the average annual costs aggregate about 54·4d. per train-mile for 6-car trains with 300 seats, or $\left(\frac{54 \cdot 4d.}{300} = \right) 0 \cdot 182d.$ per seat mile, or 9·1d. per car-mile.*

On well patronised routes, and by the exercise of great experience and strict supervision and organisation, this cost may possibly be reduced to 0·17d. per seat-mile, but, since with the present level of fares—which average in London †0·6d. per passenger mile—it has heretofore proved impossible to bring the receipts above 0·19d. per seat mile, and since in most instances even this figure has not been attained, it is evident that the margin of profit is exceedingly small with such a service when provided by the present standard system with electric trains.

Mr. B. J. Arnold in his report No. 7 (issued on Dec. 31st, 1908) to the Public Service Commission of New York City, publishes a carefully prepared analysis of the operating and fixed charges for the New York Subway. On this road there are two services, one consisting of 8-car express trains and the other of 5-car local trains. Mr. Arnold's results are given in cents. per car-mile, but in order that these results may be better compared with the results of the above study of Roads "A" and "B," the author has translated Arnold's results into pence per train mile for the equivalent in 6-car trains, and this will not introduce any appreciable error, since Arnold's data relate to a mixture of 5-car and 8-car trains. Arnold's data is arranged in three columns; the first relates to the present subway; the second relates to the utmost savings which he considers remotely

* On the New York Subway the receipts per car unit average 12d. but although the fares average a little under 0·5d. per mile, the accommodation provided is more limited relatively to the passenger mileage of traffic handled. Thus Arnold points out that during the rush hours, the strap hangers greatly exceed in numbers the seated passengers, and in his Report No. 6 (Dec. 31st, 1908) he gives tests indicating that for the whole day the passenger mileage is not much less than the seat mileage, whereas on the London underground railways the annual seat mileage is some three times the passenger mileage.

Cheap and rapid transit is of the utmost importance in every community. It affects the value and rating of property, the housing problem, and all industrial, commercial, and professional activity, and therefore the prosperity of every individual. The conservation of human effort and time is of even greater importance than that of a nation's mineral resources. Intermittency in transport services involves colossal waste of both time and effort. The rate of fares prevailing in London is tending to increase, yet the cost of getting about London is already higher on the average than it is in New York, where the fare for any distance is 2½d. (equivalent to about 1d. in London), and in Paris, where the fare is 1½d. London badly needs more effectively rapid transport facilities at lower fares, and this would be of inestimable benefit to the community.

feasible, and the last column contains Arnold's estimate for a hypothetical new subway.

				OPERATING COSTS		
				Present Subway. d.	Possible Saving. d.	Future Subway. d.
Maintenance of way	..	..		3.54	0.54	3.00
Maintenance of equipment	..	..		5.60	0.81	4.79
Maintenance of power plant	..	..		1.05	0.30	0.75
Wages of trainmen	..	..		5.37	0.12	5.25
Wages of station men	..	..		2.52	1.02	1.50
Other transportation expenses	..	..		2.85	1.20	1.65
Power expenses	..	..		7.15	0.60	6.55
General expenses	..	..		2.07	0.75	1.32
Total operating expenses (per 6-car train-mile)				30.15	5.34	24.81

COMPARATIVE FIXED CHARGES.

				Subway similar to present Subway d.	Possible Saving. d.	Future Subway. d.
Interest on permanent way	..	..		12.0	6.0	6.0
Sinking fund for permanent way	..	..		3.0	1.5	1.5
Interest on equipment	..	..		9.0	3.0	6.0
Total for fixed charges (per 6-car train-mile)				24.0	10.5	13.5

SUMMARY.

				d.	d.	d.
Total operating charges	..	..		30.15	5.34	24.81
Total fixed charges	..	..		24.00	10.50	13.50
Total cost including both opera- ting and fixed charges (per 6-car train-mile)				54.15	15.84	38.31

As to these results for the total cost Arnold states that since the lowest limit (last column) can only be secured by strict economy in investment and in operation, which in some cases might reduce the quality of the service supplied, it will be better to assume a medium figure of between 42d. and 45d. per train mile (6 coaches) as the lowest practicable limit which can eventually be expected for future new subways. He states that with the present New York subway it will be difficult to introduce sufficient economies to reduce the total cost per train-mile (altering Arnold's figures from cents per car mile to pence

per train mile of 6-car trains) to less than 52·5d. This would be $\left(\frac{52 \cdot 5d.}{300} =\right)$ 0·175d. per seat-mile, and should be compared with the 0·17d. per seat-mile which, at the conclusion of the study of Roads "A" and "B" is stated to be the lowest reasonably attainable figure with electric trains in a service with two stops per mile, and a schedule speed of 16 m.h. Thus the ultimate results arrived at from the lowest limit of cost with electric traction are about the same in London as in New York, and there is obviously something more fundamental than individual caprice in the matter of design and operation, which leads to this definite limit of cost for city, urban and suburban frequent-stop electric train service.

The author now submits in respect of the electric train system that the fundamental cause of its inherent limitations, its excessively high initial and operating costs and its consequent inability to meet adequately the requirements of the dense traffic usual in all large cities, is its characteristic "Intermittency."

In conclusion it will be of interest to refer briefly to Fig. 19 giving a diagrammatic layout of our most modern passenger transport system. We see that it involves a fourfold power plant equipment, one class of which has to be mounted on the trains and therefore has to be hauled around the route incessantly. We need not recapitulate the detrimental results of this necessity, but let us note from Fig. 20 what becomes of the energy delivered from the power house switchboard. Approximately one half is dissipated as heat waste in the electrical equipment. About one third is lost at the brake blocks, where incidentally it destroys the rolling stock, etc. The remaining sixth is used in overcoming the resistance of the heavy trains, in the weight of which the passengers account for less than 5%. Thus of every thousand pounds weight of coal purchased by the railway companies for the generation of train-propelling power (assuming the conversion from the heat in the coal to electricity on the switchboard is accomplished at an efficiency of 10%) only about one pound is attributable to the weight of passengers, the remaining 999 pounds is absorbed in hauling and braking the trains and in equipment, transmission and conversion losses. Since therefore the value of the "absolute" (or overall) efficiency is too ludicrously low for expression in tangible terms, the process may be likened to a pea on a drum. Although straying very far from that "Simplicity," which, in the words of James Watt, "is in all things, but proverbially in mechanism the supreme of excellence," engineers are not to be reproached for the extreme complication comprised in modern electric railway equipment and resulting so uneconomically. On the contrary

they are to be congratulated in so far overcoming the colossal difficulties incidental to the promoter's* call for the best solution of the problem on the *intermittent plan of operation*.

In view of the future, which undoubtedly demands better, more and cheaper transit facilities in the interest of the community, recourse must be made to the *more sensible continuous plan*, because, as the author has elsewhere endeavoured to show,† the difficulties attending the present cumbersome method do not exist, consequently the prospects of superior attainments in that direction are relatively much brighter. The Author desires to express his acknowledgments and thanks to Mr. Hobart—who kindly placed valuable data and advice at his disposal for the preparation of this paper.

* It is a debatable point as to who does (or shall) decide upon the plan to be adopted in solving future transport engineering problems.

† Royal Society of Arts, Dec. 15th, 1911, "Continuous Service Passenger Transportation in relation to the London Traffic Problem."

ADDENDA.

A. (*See top of page 156*).—This characteristic of the sub-surface traffic flow is largely due to the nature, quality and cost of the transit facilities provided by the train system. If in lieu thereof there existed sub-surface facilities giving greater comfort and much cheaper and more continuous transit at 16 m.h. schedule speed from stations located every quarter of a mile along the route and within 20 secs. access to and from the street, the traffic flow would be much more regular. A uniform penny fare within the 5-mile radius would then be possible, whilst the street congestion due to the motor bus would be eliminated.

B. (*See page 156*).—This figure is decidedly on the low side for the service under consideration. If instead of 15-sec. stops (which is too short a period for the "rush hour" service) 20 secs. be allowed, the input to train motors would be 78 w.hr. per ton-mile.

C. (*See page 159*).—It will be noticed that no item has been included in Capital Expenditure for Power House and H.T. Transmission. The figure of 0·6d. per kw.hr. is assumed to cover all charges incidental to the power supply to sub-stations.

This figure may possibly be considered as being excessive, but it does not materially affect the soundness of the conclusions made in this paper because the energy consumed in lighting, operating lifts, ventilating etc. (amounting to fully an additional 20 per cent. for Road A and considerably more for Road B) has been neglected, and moreover, no allowance has been made for maintenance and renewals on these items. These omissions therefore practically offset any reasonable reductions on the above price per unit for power, generated by a modern steam plant.

D. (*See page 160*).—The C.L.R. cost per 6-car train mile is 58·62d. taking for fixed charges, sinking fund, etc., at 4% on three-quarters of capitalization. The receipts from passenger traffic are 54·2d. to which must be added receipts from advertisements, etc., 4·5d., making the total receipts 58·7d. This is a poor return, but it is very much better than those of the London Electric Railways.

DISCUSSION.

Mr. A. W. Gattie said he had studied the great subject of transport in the Metropolis, though not in the same direction as the author, but in regard to goods transport. It seemed to him that the author had made out an overwhelmingly strong case. He did not quite grasp all that the author proposed to do, but had no doubt that the obvious objections to the scheme, objections which at once arose in the mind of anybody to whom the scheme was first introduced, had been foreseen and overcome. The paper showed how thoroughly the author had gone into the subject, and everybody would wish him the very best success in carrying out his proposals.

It appeared to him that the Corporation of the City of London might be approached and have the scheme explained to them; for the advantages were so great that they would probably give it a friendly reception, as he believed the County Council had already done. It was conceivable they might see their way to finance a real test, say a $\frac{1}{4}$ mile of railway on the Adkins-Lewis system. It would be interesting to know what curves there would be on the railway, and also to learn the method of turning the curves.

Mr. E. Benedict said there was no doubt that the author had proved the existing arrangement to be a very poor one both financially and for the purposes for which the lines had been laid down. The railways at present could not possibly carry sufficient traffic to pay a proper dividend on the capital, even if the capital had been less inflated than it necessarily had been. Very little allusion was made in the paper to the author's own proposal for overcoming or minimising those difficulties and expenses, so that it was unnecessary to say very much on that point. He had heard the lecture at the Society of Arts, where he went as a non-believer, but came away thoroughly convinced of the soundness of the proposal. Whether the inherent difficulties of introducing a new system in London could be met was a matter that could only be definitely stated after a good deal of consideration. He himself thought the difficulties were almost insuperable, but he had no doubt that the author, with his energy and youth, would be able to do a great work in that direction. It was necessary to take into consideration the lines already existing and the possibility of the amelioration of the troubles under which they laboured, and probably if the author could show the underground and tube railways how to improve their present service it would be a diplomatic way of approaching them. He thought there was every prospect of his being able to give very good advice to the present electrical undertakings both on the surface and in the tubes. Meanwhile it behoved all who were interested in the transport of London to assist in every

way to push forward the author's scheme, of which the merits were undoubted.

Mr. B. E. Dunbar Kilburn said there was one curve which the author might with advantage produce, taking as his data time and facilities for transportation. Less than a hundred years ago the only means of transport was the ordinary horse vehicle. Then, very reluctantly, came the steam train, which slowly improved. Then there was a long gap, and it was not much more than ten years ago that the first tube service was introduced into London. During the past twenty years there had been a remarkable acceleration in the facilities for transportation, and it seemed to him that the author was going to provide acceleration of that acceleration if his system was introduced, as he hoped it might be. At each stage of facility of transport the public appeared to think that finality had been arrived at, at any rate for a time, but very soon that idea was disproved. There were motor-propelled vehicles on the roads now, and any consideration of the subject of transport at the present day necessitated very fine details being dealt with. The problem had got far beyond the conveyance of men or goods from one point to another, and even beyond conveying them as rapidly as possible. The problem now to be considered was acceleration, especially in regard to the time which was involved in getting a man from his house or his business premises to the means of conveyance on his journey. He thought it was obvious the public demanded that speedy service. At first the public considered the tube railway to be a rapid way of getting about, but now they could be seen running to catch a lift or a train, although there were only a few minutes between each. Obviously, if people did that they were prepared to take advantage of every facility to save them running and assist them in getting to the trains. The author had dealt with a most interesting problem, and appeared to be solving it in an intensely interesting way.

Mr. E. Benedict said there was just one point about the acceleration he should like to mention. Years ago Sir Frederick Bramwell said that his idea of acceleration and deceleration was that of a swing, where the acceleration was very great in a short time, and the deceleration occurred without any shock. If a speed curve of that kind—a pendulum curve—could be arrived at, it would be undoubtedly the best solution.

Mr. H. E. Wimperis said he had an opportunity of talking over the matter with the author some months ago, and had known generally for some time what was being aimed at. There was a remark, he believed, of Steinmetz quoted by the author, that although the one object was to get people as quickly as possible

from place to place, it was inconvenient to start them instantly into motion and to stop them instantly. That, of course, was the case, but, nevertheless, it was necessary to get people as quickly as possible into motion and stop them as quickly as was consistent with safety. If a train started with a high acceleration, as was customary with electric traction, where a fairly heavy current was put on, raising the acceleration almost instantly from zero to an amount of the order of 2.f.s.s.—that sudden jump of acceleration was of the nature of a *blow*; and it was therefore necessary to lower the rate at which the acceleration was obtained. If sudden acceleration be compared to a blow, the gradual acceleration of acceleration proposed by the author, or what the speaker would prefer to call the velocity of acceleration, was something in the nature of a steady push. It might be likened to the difference between being kicked out of a house and being gradually pushed out.

The present method of stopping trains was, in its suddenness, about as bad as it could be. The rate of deceleration was far higher than the acceleration, far higher than anything mentioned in the paper in most cases, and it had the disadvantage that it was destroying kinetic energy which had been paid for at a heavy price. Some while ago he made a few calculations on this subject, and found that they generally confirmed the author's figures. For instance, he took a train running on a service where the stations were half a mile apart, and he assumed the train would be running at 20 miles an hour when the brakes were put on. He found the total energy necessary to move every ton weight of that train from place to place was 28 foot-tons, of which only one-half was usefully used in overcoming the resistances, the other half being spent in grinding up cast iron and spoiling the tyres and rails. That represented a very normal state of affairs to-day. If the distances between stations were to be decreased, or if the average speed were to be raised, by far the greater proportion of the energy supplied would be lost in the braking. This was a very undesirable state of affairs. It was necessary to find some suitable form of regenerative braking, and he did not feel the least doubt that the progress of electrical transport, or transport of any kind in crowded cities, had reached a point at which some means of restoring to the power station the energy lost in braking would have to be found. The author had proposed a scheme for doing that, and there were other schemes as well. He himself was present in that room only a few weeks ago, and heard an electric scheme put forward by Messrs. Macfarlane and Burge for doing the same thing.

He felt bound to criticise Fig. 17 because the author calculated on a braking retardation of only $1\frac{1}{2}$ m.h.s. No train, either steam or electric, was braked at so slow a rate. He had made numerous experiments on acceleration and deceleration for

trains, and had found it was always a great deal more than that, usually being 4 to 6 f.s.s. It would be interesting to see how the curves in Fig. 17 would be affected when that correction was made and when the unnecessary assumption of a "frictionless run" was eliminated.

With regard to Fig. 18, there was also a little difficulty. There were three curves, the bottom one being practically flat, and probably intended to be flat, which apparently would mean that, however high the acceleration was, there could never be a crest speed lower than about 20 miles an hour. He did not see why the crest speed should not tend to coincide with the schedule speed in the limit.

On page 154 the author took the friction up to the point of cut-off at 14 watt-hrs. per ton-mile. It so happened that if the number of "watt-hours per ton-mile" were divided by 2 it always gave the resistance in "lb. per ton," equivalent to that amount of electrical energy at the wheels. This would give in this case 7 lb. per ton for train resistance, which seemed to be lower than the train resistance of any electric train. The possible explanation lay in the reference to a former figure on the previous page of 15·3, where the author spoke of the "friction energy" being 30·6 watt-hrs. per ton-mile. That perhaps was the root of the difficulty. Watt-hrs. per ton-mile were not *energy*. Watt-hours per ton-mile were of the nature of a *force* per ton of train. If, therefore, there were a force of 30·6 units per ton of train and the run were divided into two parts, it was not fair for the author to say, as he seemed to do, that there were 15·3 units of force at the beginning and 15·3 at the end. On the contrary, there were 30·6 all the while. Energy is divisible in this way, but not force. But he did not know that these criticisms affected the author's argument in the main.

He agreed with him that the acceleration should be graded, that the third differential should be taken into account. He questioned whether it was necessary to consider the fourth or the fifth. The present system of starting electric trains was so barbaric that the first step the author proposed would meet all human needs for the time being.

Mr. H. H. Gordon said that they were indebted to the author for calling attention to the difficulties underlying the operation of a system of transport from which in earlier years a good deal was hoped. The great trouble, as the author mentioned, was intermittency, which might be divided into two parts; first, the mechanical intermittency, with which he felt sure the author would deal in a satisfactory manner, and, secondly the human intermittency, which caused an enormous difference between the rush hour on one day and on another, the number of passengers in any particular train being dependent on the state

of the weather. The latter problem, he ventured to think, was one that would not be so readily and satisfactorily solved as the former.

In one way the author far understated his case. A through speed of 15 m.h. on electric trains was not so important from the passenger point of view. What was important to the passenger was the time elapsing between the start and the end of his journey, in connection with which there was considerable waste of time, forming an appreciable portion of the whole time and enormously reducing the through speed of the journey. He had recently made an interesting experiment. A friend and he were at Liverpool Street Station. Both lived somewhere near Maida Vale, and he suggested to his friend that he should go by train from Liverpool Street Station to Charing Cross, step across to the tube and go on to Edgware Road, while he himself would go all the way by motor 'bus from Liverpool Street, changing 'buses at Charing Cross. This was done, and he arrived five minutes earlier than his friend, and certainly travelled much more comfortably. He asked his friend to count the number of paces he walked, and found that in station buildings he walked nearly half a mile; that is to say, from the station entrance to the booking-office, from the booking office down the stairs, from the stairs into the train, and from the train to the exit—ignoring for the moment the crossing from Charing Cross Station to the tube station. It might be argued that in the case of a journey from Liverpool Street to Charing Cross the train made a great circle, and that the line was badly located for serving London at the present time. That argument, however, did not apply to the tube railways, which had been built only comparatively recently.

Every passenger going by a tube railway had to add at least 4 minutes in getting from the street to the train and from the train to the street at the other end. A speed of 15 m.h. was mentioned in the paper for the tube railways, and that meant a mile in 4 minutes with two stations per mile, but if a man was only going a mile it took him 8 minutes, while the motor 'bus would do a mile in $7\frac{1}{2}$ minutes. The average speed of motor 'buses in London was $7\frac{1}{2}$ to 8 miles per hour. Therefore the net effect was that probably over a million of money had been spent in putting down a mile of tube railways, and as a result, although the nominal through speed was 15 miles an hour, for short distances the railway was less effective than the ordinary motor 'bus.

The subject was of tremendous importance in studying the problem of London transit. Taking the enormous number of people who travelled on the L.C.C. tramways and the tramways in Greater London, 25 per cent. of the 700 million passengers did not even travel a mile, while 50 per cent. of the total did not travel two miles. Therefore, more than 75 per cent. of the pas-

sengers in the whole of London (and he believed that this was characteristic of motor 'bus traffic too) made journeys of less than two miles. It appeared clear that on account of the mechanical imperfections of the tube system, and the mechanical difficulties to which the author had referred, it was impossible to hope for any solution of the traffic difficulties of London from the tube railway service as it now existed. He readily admitted the great convenience of the tube railways for long distances, but, after all, the 75 per cent. of passengers travelling short distances had to be considered, and if 75 per cent. of the traffic was short-distance traffic he was simply appalled at the large amount of money that had been spent in recent years in the construction of a number of tubes. It was not merely that for short distances one did not travel at any greater speed than the motor 'bus, but one did not travel with an equal amount of comfort. In his journey to Edgware Road Station he had to walk across the road from one motor 'bus to the other while his friend had to walk nearly five-eighths of a mile, taking the distance he had to travel from one station to another.

A system of shallow surface trams was far more likely to meet the short-distance traffic requirements of London than any other system. He admitted fully that he had not had the opportunity of studying the paper that Mr. Lewis had read before the Society of Arts, and, subject to what influence a study of it might have, he certainly thought that a system of shallow surface tramways, such as was installed under Kingsway, was a system which was most likely to meet the traffic requirements of the Metropolis. A tramway system seemed to him to have conspicuous advantages over the tube railway systems. A modern L.C.C. tramcar weighed 15 tons and carried 78 passengers with conductor and driver, or about 400 lb. per passenger-seat instead of 1,000 lb. as in the electric trains. As far as he was able to make out from a rough calculation, it appeared to him that, apart from the capital charges, the cost per seat-mile in the tramcar was about 50 per cent. less than the figure given in the paper. Although he believed a system of shallow surface traction would largely help to solve the problem, he thought that after all one must look to the fact that there would be always a large amount of traffic on the streets, and for that a central authority was required to deal with the development of transit facilities.

It appeared to him London was hopelessly behindhand. Each inhabitant of Paris and of Berlin travelled more than twice as often as the Londoner, though the population of Paris and Berlin was only about half that of London. He believed no one really realised the amount of monetary loss caused by the delay in London traffic. He had been trying to work out how much money it amounted to when he saw a stream of traffic, extending from the Bank down to Liverpool Street Station, completely

blocked. A debt of gratitude was owing to all who were doing their utmost now in endeavouring to solve the problem, because they were doing work which was in the true interests of the development of London as a great city.

Mr. Benedict asked whether, in calculating the number of short-distance passengers at 75 per cent., Mr. Gordon had taken into consideration workmen's tickets. If the calculation had been made on the number of penny tickets, workmen's tickets would spoil the calculation altogether, because most workmen certainly went more than a mile.

Mr. Gordon said the 25 per cent. halfpenny fares were clearly not workmen's tickets. Workmen's fares were included in the 50 per cent., but even making allowance for that the overwhelming bulk of London traffic was less than 2-mile journeys.

In 1909-10, out of 451,000,000 passengers carried on the L.C.C. Tramways, 42,000,000 were carried at workmen's fares. Even assuming that all workmen travelled over 2 miles it is still a fact that 72 per cent of all the remaining passengers travelled two miles or less.

Mr. Angus wished to supplement the experience of Mr. Gordon because quite recently he had made similar experiments on the Central London Railway, with the invariable result that the motor 'bus had beaten the train, owing to the long delays on the lifts and the lengths of passages to be traversed. He had tried it from different stations, and always with the same result. There was 10 to 15 per cent. in favour of the motor 'bus.

Some disparaging remarks had been made about the unfortunate man in the street who ran to catch trains, but it should be remembered that the present times were so hard that every moment saved represented a certain amount of money gained, and every moment lost represented a loss to the pocket. Therefore if the author could only substantiate his project and produce something that would get a man to his destination much more quickly he would have the gratitude of the whole community of London.

Mr. Dunbar Kilburn said he was not at all deprecating the fact that a man had to run for the train, because he frequently did it himself. He had only remarked upon it as an item in the development of present-day life that people were prepared to run for a train even in these days of rapid transit. With regard to time lost, on a journey which he had been in the habit of making for years on the Central London Railway between Lancaster Gate and Chancery Lane, he had been struck by the time occupied in going down and coming up as compared with the actual travelling time from point to point. There was really an appalling waste.

Mr. Hucks said he had great faith in the author's project, and had come that evening with the idea of hearing some criticisms that might cause him to think the author was a little over-confident in his suggestions. But as far as he could see he should leave the meeting with a similar belief in the proposition to that which he had when he came in.

Mr. A. S. E. Ackermann said that one or two speakers had referred to the author's paper at the Society of Arts, but had not given any hint as to what proposal was then put forward. Roughly speaking, the system proposed by the author was as follows :—The carriages of his train were kinematically equivalent to a nut on a screw, a rotating screw being the means of propelling the coaches along the track. The pitch of the 'screw' decreased greatly at the stations and increased greatly between the stations, so that the train went through the station at a much slower speed than it went between the stations. An advantage of the author's system was that some of the lost energy, amounting to something like 80 per cent., now absorbed in tearing up the track and grinding down the wheels and brake blocks would be given back to the screw, for as the "nut" was decelerated at the stations it would press against the screw threads and help to drive the screw.

With regard to the possibility of accidents, the "nuts" or carriages would always be a certain distance apart, varying, of course, on account of the difference in the pitch, but one could not conceive an accident happening by collision.

The fact that the carriages were never brought absolutely to rest meant that there would be no statical friction to overcome, as there is in the case of trains which are brought to rest and then have to be restarted. There was an enormous difference between statical and dynamical friction, as everyone knew who pulled at something which was stuck, and which then suddenly gave way! The moment statical friction was overcome things moved with very much less friction. By keeping the thing only just moving there was no statical friction to overcome.

With regard to the feasibility of getting into and out of trains moving at a slow rate in the stations, those who had the advantage of seeing the magnificent Exhibition in Paris in 1900 would remember the moving platform. The platform was in three horizontal sections, raised about 12ft. above the street level. One section was an ordinary fixed platform along which one could walk at leisure. The next section moved at $2\frac{1}{2}$ miles an hour, and beyond that there was the third section moving at 5 miles an hour. The public became so familiar with the platform that certain of the younger members of it were not content with stepping on to the first speed at $2\frac{1}{2}$ miles an hour, but used to jump clean over that portion of the platform on to the five-mile one!

That showed that the tendency of the public was to avoid moving slowly when they could move quickly. The moving staircase at Earl's Court Station was another example of something which the usual opponents of progress would undoubtedly have condemned as impracticable and unsafe had they had the opportunity, but they were saved from trouble by the thing being *done*, and proved a success before the pessimists even heard of it !

Mr. W. P. Durnall said that the question of obtaining economical acceleration and retardation of trains was a very serious matter, and the retention of old-fashioned methods was a reflection on British engineers ; while the poor dividends paid by railways, tramways, and other means of transport which had adopted electrification in one form or other, showed what a low efficiency still obtained.

The screw proposed by Mr. Lewis provided for gradual acceleration and deceleration together with the recuperation of the kinetic energy in the moving car, etc. As an electrical engineer he would like to know whether Mr. Lewis had considered an alternative scheme, in which variable frequency and voltage polyphase alternating current, with squirrel-cage motors, would be substituted for the variable pitch thread on the screw.

REPLY.

The Author, in reply, said he was somewhat surprised that exponents of electric traction had not in self-defence taken a greater part in the discussion. Several had been specially invited to do so, and the paper had been widely announced in the Press. The fact of the matter was that the paper comprised a truthful survey of the electric train system. The figures given and the conclusions drawn were reasonable and fair. The case against intermittency could easily have been made much stronger. He had selected the standardised 600 volt direct current equipment as instanced in London, and had treated it favourably. Possibly the 1,200 volt direct current equipment as instanced on the new Nord-Sud Line in Paris would make a slightly better showing, but the single-phase alternating current method of train operation would certainly make a worse showing for the service considered, whilst the effect of intermittency upon electric tramway and motor 'bus services was in many respects even more detrimental.

He did not wish to belittle the endeavours and attainments of those who were in any way associated with the provision of transport facilities, nor was he unmindful and regardless of others' interests, his motto being *Sic utere tuo ut alienum non lēdas*. He had been a humble student of transport for over twenty years, and had been profoundly impressed with the possibilities of the continuous plan of operation by what he

learned in Paris in 1900. In the following three succeeding years he had been enabled to grasp the difficulties attending the attempt to meet the requirements by the provision of electric trains operated intermittently, as he was engaged in the construction and equipment of one of the London tube railways, and had, in conjunction with others, to make all the calculations and estimates pertaining thereto. In the meantime he had closely studied the problem in London, and in several American and Continental cities, and felt that the time had now come to open up developments in a direction which appeared to hold prospects of infinitely superior attainments.

He would like to reply first of all to the remarks of Mr. Wimperis, who was on the Council of the Institution of Electrical Engineers, and who had recently invented a very useful instrument for recording accelerations, which was referred to in Fig. 12. He thanked Mr. Wimperis for emphasising the detrimental features of braking in substantiating the figures given in the paper. He had heard of several schemes put forward to secure regenerative braking action—but few of them seemed to materialise on electric railways. The electric train system would be by no means “out of the wood” even if perfect regenerative braking could be attained. Schemes with this object in view have the disadvantage that since the motors serve not only to propel the train, but also as generators during braking, they have to carry current for a much greater proportion of the time. Consequently the motors must be larger and heavier so as to avoid overheating, or be fitted with forced ventilating apparatus, which meant further complication and deadweight carried. Electric traction enthusiasts were a little too prone to over-estimate their capabilities, and their discussions upon railway matters have even been characterised by a “reckless disregard of mechanical considerations” to such an extent that only very recently an able paper (Inst. of Electrical Engineers, “The Mechanics of Electric Train Movement,” by F. W. Carter, April, 1912) was delivered “as a protest against the presentation of biased estimates,” and “as a plea that the Institution of Electrical Engineers should insist that the discussion of the subject be made on the basis of reason and fact alone.”

He was quite aware that it was usual to employ higher decelerations than $1\frac{1}{2}$ m.h.s., as given in Fig. 17, and everybody felt that the rate of braking was uncomfortably high, but the rate taken, coupled with the neglect of deceleration during coasting (i.e., “frictionless run,” not an “unnecessary assumption” when, as in a paper of this kind, it is desirable to curtail the calculations as much as possible) gave the equivalent crest speed for the higher braking rate, taken in conjunction with the loss of speed due to train friction for the period when the current was

cut off. The curve given would be found practically true for actual running conditions.

He was very glad Mr. Wimperis had commented upon Fig. 18. Those curves contained a fund of information, and clearly indicated the serious limitations of any intermittent service system as regarded attainable speeds for given runs. They were substantially true, and Mr. Wimperis' surmises were quite correct. They showed that for a half-mile run with 20-sec. stops a schedule speed of 15 m.h. could not be provided unless the mean acceleration and deceleration was in the neighbourhood of 1 m.h.s.; also that the crest speed could not be less than 20 m.h. under present operating conditions, and further that 20 m.h. schedule speed was unattainable. The crest speed did not "tend to coincide" with the schedule speed, and were Mr. Wimperis to work out results for schedule speeds of, say, 9 and 18 m.h., he would find that by doubling the schedule speed, the crest speed would be considerably more than trebled, whilst the energy consumption would be more than eleven times as great for 18 m.h. as for 9 m.h., even when the efficiency of the electrical equipment was assumed to be 100 per cent. and the train friction altogether neglected.

With regard to Mr. Wimperis' remarks on the energy for overcoming train resistance, he had, on page 152, moderately taken 7 kg. (15·4 lb.) per ton as the tractive effort necessary. This figured out to require the energy consumption given, and the train drew about half of it from the power supply and the other half from its own momentum, losing speed thereby. It was not that the train required only half the "force" to overcome its resistance, the tractive effort remained more or less constant so far as related to frictional resistance to motion, and he felt sure he was correct in dividing up the energy consumption as given approximately in the paper. Surely the watt hr. was a measure of energy, not "force." Watt hours per ton mile could be reduced to watt hrs. per ton per hour, which meant watts per ton—a power unit indicating the rate of energy consumption. Mr. Wimperis seemed to confuse that with what was erroneously called "force" by him. It was not "force," but energy consumption that had been divided up on pages 152 and 154. Another method of treating the matter would have been to multiply the watt hrs. per ton mile by the respective distances covered to get watt hrs. per ton, and to have worked out the average rate of consumption per ton over an hour for each item, wherefrom percentages could be figured. The process would have been more laborious, however, and the results would not have differed seriously from the approximation made in the paper.

He did not agree with Mr. Wimperis that it was unnecessary to graduate the acceleration beyond the third differential, although, so far as the comfort of the passengers was concerned,

no doubt it would be sufficient. Electric traction engineers would find even that attainment rather difficult of accomplishment. A study of Curve D in Figs. 8, 9, and 10 clearly indicated that enormous advantages followed graduation to the fourth differential. This could be quite easily attained in the Adkins-Lewis system, and, regarding the comfort of passengers, it merely remained for physiologists to enunciate the law of most congenial acceleration and deceleration, since the driving shaft spirals in that system could be designed in conformity therewith, whether it were in the nature of Mr. Wimperis' method of clearing his friends out of his house, or of Mr. Benedict's delightful idea of "swinging" mankind.

In reply to Mr. Dürtnall, who had mentioned having worked upon a scheme to provide a continuous series of cars operated by variable frequency current, he had worked on those lines himself, and had met several who had been doing so, including Mr. Frank Sprague, with whom he had several talks on the subject in New York, and Mr. Campbell Swinton here in London. The prospects in that direction, however, were not at all bright for many reasons, and it was inconceivable that a succession of cars at high speed and close time-intervals could be sufficiently well and positively controlled to warrant adoption on the score of safety. The objection to carrying driving equipment on the cars and costly labour to operate same were clearly set forth in the paper.

He was particularly glad to hear the remarks of Mr. Gordon, who evidently was devoted to the study of the London traffic problem. The points about human intermittency greatly interested him, and he would direct attention to Addendum A on page 164. The variation in the traffic flow from day to day was undoubtedly due in part to the weather conditions. Surface conditions were adversely affected by wet and foggy weather, whilst the sub-surface routes benefited thereby, but he believed that all existing facilities suffered by the very nature and cost of the service they provided. They were themselves direct incentives to rush-hour characteristics and variations in the volume of the human streams from day to day, whereby the whole community, especially the traders, suffered in consequence. The subject was one he intended to deal with fully in a later paper.

Mr. Gordon's journey time tests and those of Messrs. Angus and Kilburn were very interesting. He had made several similar ones himself and had embodied the results in his Society of Arts paper. It was undoubtedly true that there was in the aggregate a colossal waste of time and effort going on in London, and it should be remembered that our waste of human time and effort was infinitely more serious than even our waste of national material resources. He assured Mr. Benedict that

Mr. Gordon's figures, indicating that the vast majority of journeys taken were under two miles, were quite correct. The number of journeys per head of population was much lower in London than in New York, Paris and Berlin, where the average length of journey was, he believed, shorter, showing a serious drag in London's prosperity. He agreed with Mr. Gordon that there was no hope of much further development by Tube Railways. If, however, those that now existed would only improve their means of access between street and train (as they could easily do at moderate cost by means of the Adkins-Lewis continuous vertical and inclined elevators) they could enormously increase their effective utility and their returns.

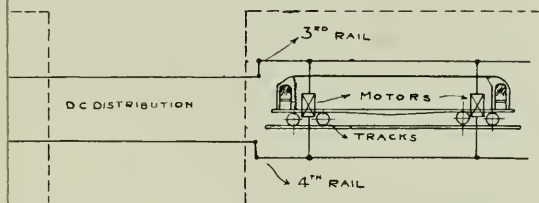
He was surprised to hear Mr. Gordon speak favourably of the comfort of motor buses. Personally he considered them far from comfortable. One got dreadfully shaken and jolted about even in the newest productions, and the seat areas provided were decidedly scant. Mr. Gordon hoped for some relief by the provision of tramways in shallow subways. That hope was absolutely hopeless. The figure of 400 lb. per seat was about right for a double-deck tramway car, but for the single-deck cars used in the Kingsway subway the deadweight would be quite 800lb. per seat. Subways to accommodate even single-deck cars had to be so commodious and therefore so costly that they could not pay one per cent. on the capital outlay, whilst the capacity and effective speed would be most unsatisfactory and there could be no prospect of lower fare rates than those prevailing. As to the cost per seat mile on L.C.C. tramways, it was of course useless to neglect fixed charges, the "lowest possibles" for various existing systems given in the author's Society of Arts paper being approximately correct.

Mr. Ackermann, Mr. Gattie and others had referred to the system that the author recently introduced and he heartily thanked all the speakers for so kindly encouraging him. He had not intended to touch upon the Adkins-Lewis System that evening, the object of the paper being to point out the detrimental features of intermittency, and to get on record, in a comprehensive way, a true story of what the electric train system was and did, so that later on he could write a similar paper dealing with the Adkins-Lewis System and draw a comparison. In his Society of Arts paper he had set forth a general description of this system with illustrations of a diagrammatic nature, but its originators did not desire to publish actual details yet awhile. Mr. Ackermann's explanation was quite good and he was very kind in giving it, particularly as he was, to the author's surprise, familiar with the moving platform system, and therefore able to substantiate the feasibility of the continuous plan. The great question to be determined was, would Londoners be able to mount and dismount the cars moving

at a constant speed of $2\frac{1}{2}$ to 3 miles per hour ? ” In order to find out the L.C.C. had kindly consented to the temporary use on terms of the Aldwych island site for the installation of a full-size railway section, which it was proposed to build and operate for public inspection and trial. This would serve also to demonstrate on a more extensive scale the practicability of the system in the negotiation of curves and grades, and other details, which quite naturally present difficulties to those who know really nothing of the proposition. It is believed that this would definitely establish the advantages which had been claimed, some of which became self-evident from an inspection of Figs. 21 and 22 in comparison with Figs. 19 and 20.

In conclusion the author expressed his thanks for the kind reception accorded to his paper, and for the support which appeared to be growing in favour of the efforts he and his associate Mr. Adkins were making somewhat under difficulties. If eventually the scheme proved to be impracticable they would feel satisfied if they could think they had done a little to help others to find a solution of what was undoubtedly an extremely important problem to the community in all large cities throughout the world.

is the minimum necessary (for propulsion
s per hour (say 12,000 seats per hour)
s per mile.



VERTERS

ROLLING STOCK WITH
HEAVY DRIVING EQUIPMENT
ON BOARD.

nsiderable in
space.

Class 4. - Plant involves very heavy
capital outlay and operating
charges.

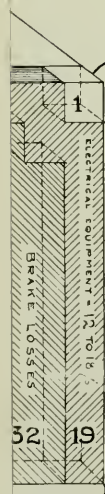
y per mile of
0 K.W.

Approximate capacity per mile of
route = 5,500 B.H.P.
(Motor Cars only.)
*

be capable of sustaining overloads of 50 %.

ELECTRIC TRACTION.

FIG. 19.



Proportion due to weight of passengers
on basis of 3 seat-miles per passenger-
mile. Thus the over-all "absolute"
efficiency of the electric train system from
power house switchboard to passengers
is only 1 %. and from coal bunkers
to passengers only 0.1 %. If, how-
ever, the dead weight of trains be taken
into account, the efficiencies are respec-
tively 20 per cent. and 2 per cent.

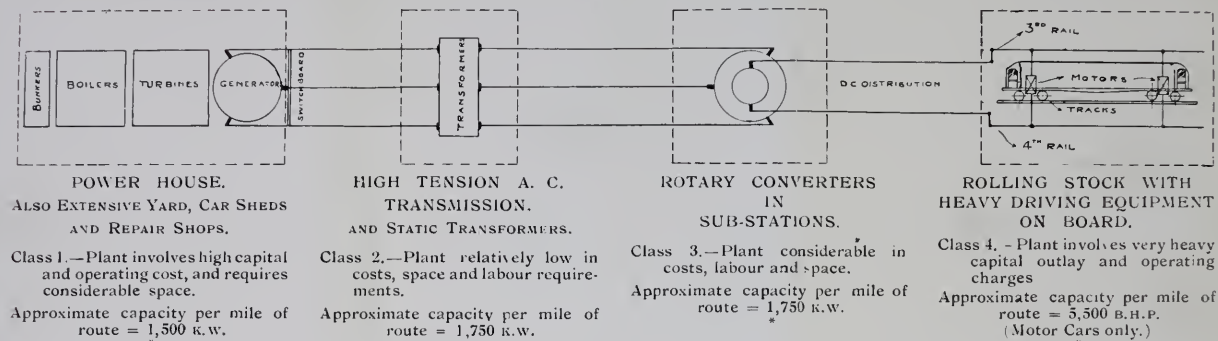
TRAINE
IN ELECTRIC MOTORS
IN BRAKE BLOCKS

SUMED BY AN ELECTRIC RAILWAY.

FIG. 20

This Diagram excludes accessory Equipment for Lighting, Lifts, Ventilating, Signalling, etc.

* The approximate capacities of Plant per route mile given for the different classes is the minimum necessary (for propulsion only) in, say, a 6 or 8-mile route, with rush-hour service of forty 6-car trains per hour (say 12,000 seats per hour) at a schedule speed to 16 M.H. with two stations per mile.

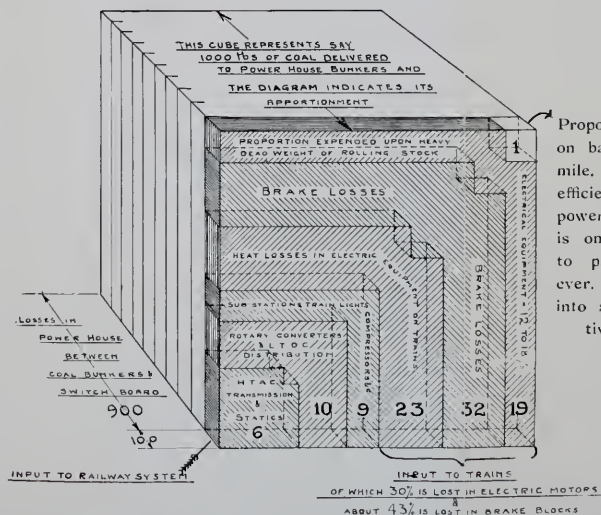


AGGREGATE PLANT EQUIPMENT PER ROUTE-MILE = 9,000 K.W. This has to be capable of sustaining overloads of 50 %.

EQUIPMENT DIAGRAM—COMPOSITE SYSTEM OF ELECTRIC TRACTION.

FIG. 19.

N.B.—This diagram does not take into account the additional energy consumed in lighting stations, tunnels, yards, sheds, power stations, &c., nor the energy required to operate lifts, ventilating fans, and the amount consumed in shunting trains and sundry losses. These incidentals amount in the aggregate to a further 40 per cent. fuel consumption.



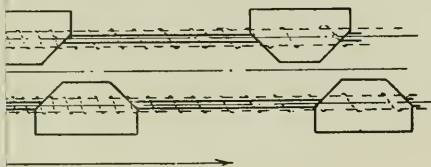
Proportion due to weight of passengers on basis of 3 seat-miles per passenger-mile. Thus the over-all "absolute" efficiency of the electric train system from power house switchboard to passengers is only 1 %. and from coal bunkers to passengers only 0.1 %. If, however, the dead weight of trains be taken into account, the efficiencies are respectively 20 per cent. and 2 per cent.

DIAGRAM ILLUSTRATING THE APPORTIONMENT OF ENERGY CONSUMED BY AN ELECTRIC RAILWAY.

FIG. 20.

ing spares) for, say, a 6 or 8-mile route,
with 4 stations per mile.

STATIONS



0 K.W.

JOUS TRANSPORT.

FIG. 21.

Proportion due to weight of passengers on basis
of 3 seat-miles per passenger mile.

Since the driving shaft performs other useful
services in addition to propelling the cars,
the energy due to its rotation cannot be
considered as wasted. It obviates signals
and brake apparatus with costly labour
incidental thereto. It also eliminates train
drivers and conductors.

Efficiency—

Input to passengers	... 5%	} Allowing nothing for the above.
Input to rolling stock	... 49%	
Fuel to passengers	... 1.7%	
Fuel to rolling stock	... 16.7%	

engines are used direct coupled.

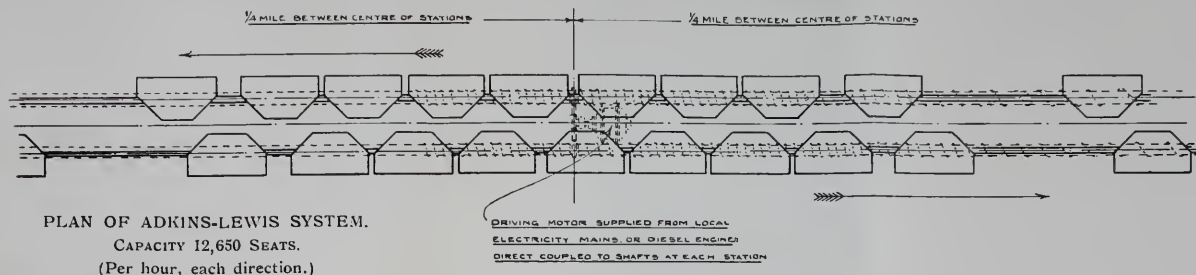
It will be seen by comparing this figure with
the similar one for the electric train system
(Fig. 20), that the Adkins-Lewis system
is distinctly superior, since for same
capacity and schedule speed, less than
one-half the subway space is required,
whilst the plant equipment is only about
one-twentieth, and labour and power
costs are comparatively insignificant, not-
withstanding which, twice as many stations
per mile are provided.

IN AN ADKINS-LEWIS SUBWAY.

FIG. 22.

This Diagram excludes accessory Equipment for Lighting, Lifts, and Ventilating.

* The capacity of plant per route mile given (for propulsion only) is amply sufficient (including spares) for, say, a 6 or 8-mile route, with rush-hour service of 12,000 seats per hour, at a schedule speed to 16 M.H. with 4 stations per mile.



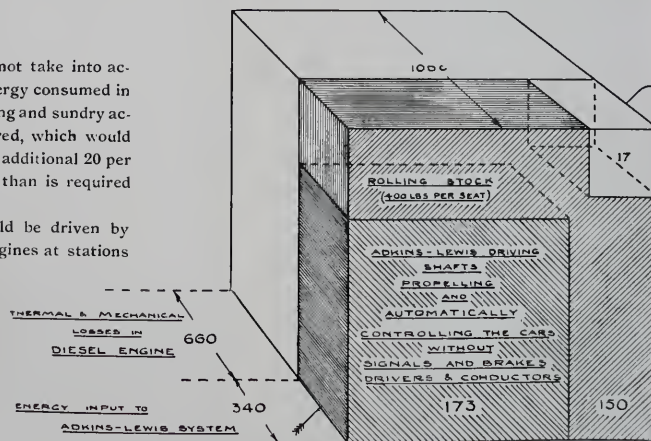
* Aggregate Plant Equipment per route mile, including spares, 550 K.W.

EQUIPMENT DIAGRAM—ADKINS-LEWIS SYSTEM OF CONTINUOUS TRANSPORT.

FIG. 21.

N.B.—This diagram does not take into account the additional energy consumed in lighting, lifting, ventilating and sundry accessories possibly required, which would not, however, exceed an additional 20 per cent., being much less than is required with the train system.

The main shafts would be driven by direct coupled Diesel engines at stations every 1/4 mile along the route, thus eliminating breakdown of power supply. The lighting and other accessory power supply would be furnished from central station.



THIS CUBE REPRESENTS 340 000
UNITS OF FUEL (OIL) SUPPLIED TO
THE SYSTEM & THE DIAGRAM INDICATES
ITS APPORTIONMENT

Proportion due to weight of passengers on basis of 3 seat-miles per passenger mile.

Since the driving shaft performs other useful services in addition to propelling the cars, the energy due to its rotation cannot be considered as wasted. It obviates signals and brake apparatus with costly labour incidental thereto. It also eliminates train drivers and conductors.

Efficiency—

Input to passengers	5%	} Allowing nothing for the above.
Input to rolling stock	49%	
Fuel to passengers	1.7%	
Fuel to rolling stock	16.7% if Diesel engines are used direct coupled.	

It will be seen by comparing this figure with the similar one for the electric train system (Fig. 20), that the Adkins-Lewis system is distinctly superior, since for same capacity and schedule speed, less than one-half the subway space is required, whilst the plant equipment is only about one-twentieth, and labour and power costs are comparatively insignificant, notwithstanding which, twice as many stations per mile are provided.

DIAGRAM ILLUSTRATING THE APPORTIONMENT OF ENERGY CONSUMED IN AN ADKINS-LEWIS SUBWAY.

FIG. 22.

RESISTANCE TO ROLLING

By HERBERT CHATLEY, B.Sc. (Engineering), A.M.I.C.E.I.

Professor of Civil Engineering, Imperial Engineering College,
Tangshan, China.

Rolling Friction.—The resistance to the rolling of one body on another has long been a subject of enquiry, but it still contains many obscurities, and it is the object of these notes to formulate certain rules for the practical estimation of rolling resistances. A large number of variables enters into the problem, but there can be little doubt that the resistance depends on the manner and extent to which the surfaces in contact are deformed, and upon the space and time rates of change of such strains.

In a theoretical discussion, therefore, there are two problems to be solved :—

- (a) The conditions of static balance of a rolling pair, consisting of cylinder and plane, or cone and cylinder. (Cylinder on cylinder, cone on cone, sphere on plane, and sphere on sphere will be soluble by analogy.)
- (b) The changes which occur in this equilibrium when a torque is applied to the moveable body, and the relation of such changes to time and position.

Before discussing these questions it will be useful to note all the variable quantities concerned. These are as follow :—

- (1) *Weight* of the roller per unit width of surface of contact. In the case of a cylinder and plane, both being true, this quantity is constant. With a cone and cylinder pair the total load must be considered.
- (2) *Radius* of the surface or surfaces in contact.
- (3) *Breadth* of the surface of contact.
- (4) The elasticity or *compressibility* of the roller, defined as the strain per unit force (I/E).
- (5) The *compressibility* of the rolling surface.
- (6) The *rigidity* or resistance to shearing of the rolling surface. The rigidity of the roller may also come into the calculation.
- (7) The static and kinetic *co-efficients of friction* between the materials of which the rolling pair is composed.
- (8) The structural *arrangement* of the materials in the pair.
- (9) The angle of *slope* of the rolling surfaces.
- (10) The linear *velocity* of the centre of gravity of the roller.

Stresses and Strains accompanying Static Equilibrium of a Cylinder on a Plane.—A mathematically perfect cylinder resting on a perfect plane depresses the latter, and is itself distorted.

The vertical stresses over the surface of contact must be equal for the two materials, and their resultant must be equal to the weight of the cylinder. Since the stresses are equal, the strains of each must be inversely proportional to the elasticities, *i.e.*, they must vary directly as the compressibilities. The ordinates, therefore, of the surface of contact relative to the undisturbed plane are a constant fraction of the ordinates to the surface of the cylinder considered as unstrained. The profile is a circular curve whose ordinates are reduced in a constant ratio. This ratio in the case of the cylinder is that of the compressibility of the cylinder material to the sum of the compressibilities of the two materials. If the two materials are equally elastic the profile of the surface of contact is half the height of the segment cut from the cylinder by the plane considered as undisturbed.

These compressive strains are accompanied by lateral expansions in accordance with Poisson's ratio. If the elasticities of the materials are different these lateral expansions will produce relative motion which, being resisted by the mutual friction, will cause shear stress.

STATIC EQUILIBRIUM OF CYLINDER ON PLANE.

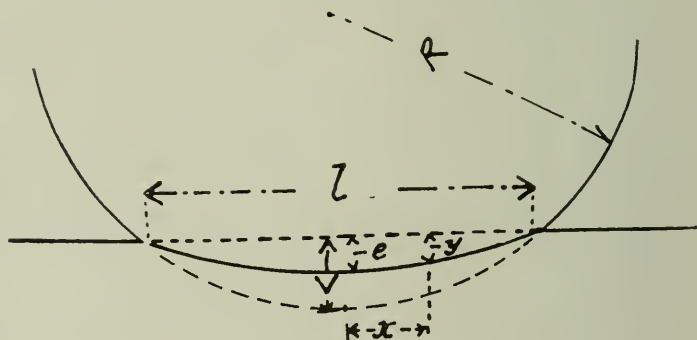


FIG. 1.

Symbols.— e = maximum depression. l = length of contact. R = radius of cylinder. θ = semi-angle of contact = $\sin^{-1} \left(\frac{l}{2R} \right)$. b = breadth of contact. W = total load. V = camber of the segment whose chord is l . $\frac{1}{m}$ = Poisson's ratio (*i.e.*, the ratio of lateral expansion to longitudinal contraction) $\cdot e = \frac{V}{m}$
 $1 - \frac{1}{m}$ = the ratio:—

Compressibility of cylinder material

Compressibility of cyl. material + compressibility of plane material

 x = co-ordinate of surface of contact (abscissa). y = " " (ordinate).

We assume the stress to vary directly as the total strain at each point and for the present neglect the horizontal components. Then the stress at any point $p = ky$, where k is a constant, and—

$$W = b \int p. dx = kb \int y. dx.$$

y must be expressed as a function of x , and is of the form—

$$y = \frac{1}{m} (V - \{R - \sqrt{R^2 - x^2}\})$$

and

$$V = R - \sqrt{R^2 - \frac{l^2}{4}}$$

$$\begin{aligned} W &= \frac{kb}{m} \int_{x=-\frac{l}{2}}^{x=\frac{l}{2}} (V - R + \sqrt{R^2 - x^2}) . dx \\ &= \frac{kb}{m} \left[Vl - Rl + R^2 \sin^{-1} \left(\frac{l}{2R} \right) \right] \end{aligned}$$

If for small values of θ we write $\sin^{-1} \left(\frac{l}{2R} \right) = \frac{l}{2R}$, we get—

$$W = - \frac{kbVl}{m} \left(\frac{R}{2V} - 1 \right) = - kb\epsilon l \left(\frac{R}{2V} - 1 \right) \quad \therefore (1)$$

Substituting for V , we get an equation for l of the fourth degree—

$$l^4 - 3 R^2 l^2 - \frac{4WR}{kb} l + \frac{4W^2 m^2}{k^2 b^2} = 0. \quad \therefore (2)$$

More convenient expressions can be obtained if we assume that y is a cosine or parabolic function of x .

If we write—

$$y = \frac{V}{m} . \cos \left(\frac{\pi}{l} . x \right) = \epsilon . \cos \left(\frac{\pi}{l} . x \right)$$

we get—

$$W = - \frac{2 x b \epsilon l}{\pi} \quad \therefore \quad \therefore \quad \therefore \quad \therefore (1A)$$

Substituting $2R \sin \theta$, for l , and $\frac{R (1 - \cos \theta)}{m}$ for ϵ , we get—

$$W = - \frac{4kb}{\pi} . \frac{R^2}{m} . \sin \theta (1 - \cos \theta),$$

and $\sin \theta$ is to be found from the following equation :—

$$\sin^4 \theta + \frac{\pi m W}{2 k b R^2} \cdot \sin \theta + \frac{\pi^2 m^2 W^2}{16 k^2 b^2 R} = 0 \quad \dots \quad (3)$$

Or, if we write—

$$y = e \left(1 - \frac{4}{l^2} \cdot v^2 \right)$$

we get—

$$W = -\frac{2 k b e l}{3} \quad \dots \quad (1B)$$

when the equation for l becomes—

$$l^4 - \frac{12 m W l R}{k b} + \frac{9 m^2 W^2}{k^2 b^2} = 0. \quad \dots \quad (2A)$$

An equation for e can also be found—

$$e^4 - \frac{2 R}{m} \cdot e^3 + \frac{9 W^2}{16 m^2 k^2 b^2} = 0. \quad \dots \quad (4)$$

Also an equation for k , independent of e (but not of l)—

$$k^6 - \frac{4 b l R}{m \pi W} k^5 + \frac{9 b^2 l^4}{m^2 \pi^2 W^2} = 0 \quad \dots \quad (5)$$

If the cosine form is used, the maximum stress is $\frac{\pi}{2} \times$ mean stress. If the parabolic form is used, the maximum stress is $\frac{3}{2} \times$ mean stress (mean stress = $\frac{W}{b l}$)

k is the only quantity which is very uncertain, and its possible values will be discussed later.

It should be noted that if $\frac{1}{m} = \frac{1}{2}$ (i.e., the compressibilities of the two materials are the same), the compressive strains are the same for both. This is a not infrequent case in practice, e.g., a steel wheel on a steel rail.

The preceding formulæ can be greatly simplified if we combine the form 1B with the well-known approximation—

$$\frac{l}{2} = \sqrt{2 R V}$$

$$\text{whence } V = \frac{l^2}{8 R}$$

$$W = \frac{2 k b e l}{3} = \frac{2 k b V l}{3 m} = \frac{k b l^3}{12 R m}$$

so that—

$$l = \sqrt[3]{\frac{12RmW}{kb}} \quad \dots \quad (6)$$

and—

$$k = \frac{12RmW}{bl^3} \quad \dots \quad (7)$$

Or, in terms of V —

$$W = \frac{2kb}{3m} \cdot V \left(2 \sqrt{2RV} \right)$$

$$\frac{3mW}{4kbV} = \sqrt{2RV}$$

$$\frac{9m^2W^2}{16k^2b^2V^2} = 2RV$$

$$V^3 = \frac{9m^2W^2}{32k^2b^2R} \quad \text{and} \quad V = \frac{1}{2} \sqrt[3]{\frac{9m^2W^2}{4k^2b^2R}}$$

so that—

$$e = \frac{1}{2m} \sqrt[3]{\frac{9m^2W^2}{4k^2b^2R}} \quad \dots \quad (8)$$

In any actual case, l may be calculated from equations (2), (3) [$l = 2R \sin \theta$], (2A) or (6); e may be computed from (4) or (8).

If l or e has been observed, k can be obtained from equations (4), (5), (7) or (8).

Thus the author's observations for steel on steel in two extreme cases (1) a car wheel and (2) a spindle carrying a fly-wheel, give results as follow:—

	R	m	W	l	b	k
(1)	20in.	2	11200lb.	0.1in.	1.0ins.	5.5×10^9
(2)	0.5in.	2	17lb.	0.004in.	0.41in.	5.6×10^9

Value of the Co-efficient of Compression.—It has been assumed throughout the preceding reasoning that the resistance to compression at each point of the surface of contact varies as the extent of the compression. This assumption is probably to some extent incorrect, because the stresses diminish as the area of action increases, but the writer cannot see any practical way of avoiding this difficulty, and it would not appear that within the limits usually considered this variation can be the source of very serious error.

There are two methods of getting at k :—

(1) By collateral observations of W and l or e ; k can then be calculated from equations (4) or (5), or similar equations based on (1) or (1A).

(2) By an analysis of the stresses throughout the depth of the cylinder or the plane, and space integration thereof.

The notes which follow will show the practical difficulty of the second method.

In the case of car wheels of the usual built-up form and rails which are not continuously supported, it might be expected that the deflections due to the bending stresses of both would affect the problem, but a calculation of the change of curvature produced on an ordinary 60 lb. rail with an 8-ton central load and a low modulus of elasticity shows that with a properly designed track the bending is negligible in its effect on rolling.

Some remarks as to its value on non-resilient surfaces will be found on page 191.

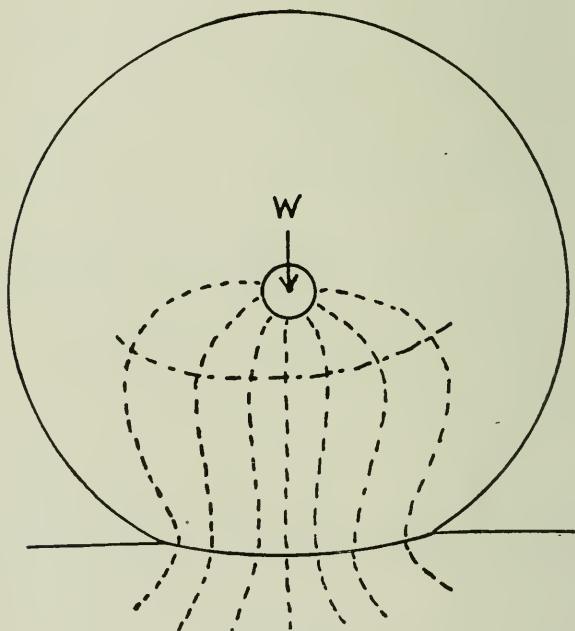


FIG. 2.

In the case of a cylinder which supports a load applied at its centre (*e.g.*, a solid car wheel) the lines of stress which analogy would indicate are somewhat as shown in Fig. 2. The locus of minimum stress evidently lies below the centre. The vertical strain would on the system supposed be rather more than, but not greatly different from, that of a semi-cylinder with an equal load distributed over a horizontal diametral plane.

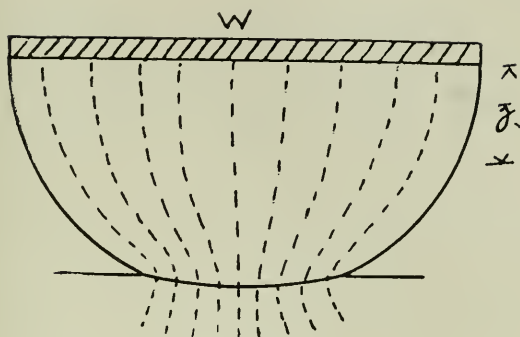


FIG. 3.

Approximately in this case the stress on any plane z below the centre is—

$$\frac{W}{2b\sqrt{R^2 - z^2}}$$

so that the mean strain over the surface of contact is—

$$e_m = \frac{W}{2E_r b} \int_0^{z=R-e_m} \frac{dz}{\sqrt{R^2 - z^2}} = \frac{W}{4EbR} \cdot \log_e \frac{2R - e_m}{e_m}$$

This can be solved by trial in any particular case, and we can then say—

$$k_1 e_m = \frac{W}{bl} \quad (l \text{ is a function of } e_m \text{ and the radius})$$

$$e_m + \frac{2}{3}e = \frac{2}{3}V \text{ approximately}$$

$$\text{and } \frac{k}{k_1} = \frac{E_p}{E_r}$$

$$\left[\begin{array}{ll} E_p \text{ is Young's modulus for the plane material} \\ E_r \text{ is } & \text{,,} & \text{for the roller material.} \end{array} \right]$$

As to the compressive strain in the supporting surface it is very difficult to say much. Some idea may, however, be obtained by the following analysis:—Let a load P rest in a mass of indefinitely large area and thickness, and *let us assume* that, owing to the continuity of the material the stresses are distributed laterally so that the actual supporting volume is a frustum whose top area is A .

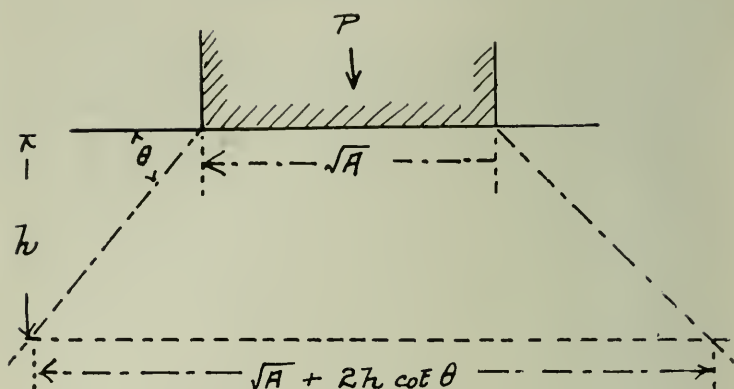


FIG. 4.

Then at any depth h the stress $p = \frac{P}{\sqrt{A + 2h \cot \theta}}$ and

$$\text{the total depression } \Delta = \int_0^h \frac{P}{E} \left[\left(\frac{dh}{\sqrt{A + 2h \cot \theta}} \right)^2 \right]$$

This integral equals—

$$\Delta = \frac{P}{2E \cot \theta} \left[\frac{1}{\sqrt{A + 2h \cot \theta}} \right]_0^h = + \frac{P}{2E \cot \theta} \times \left[\frac{1}{\sqrt{A}} - \frac{1}{\sqrt{A + 2h \cot \theta}} \right]$$

If $h = \infty$

$$\Delta = \frac{P}{2\sqrt{A} E \cot \theta} \text{ or since } \frac{P}{A} = p_{\max.} \quad \Delta = \frac{p_{\max.} \sqrt{A}}{2E \cot \theta}$$

Assuming $\theta = 45^\circ$ (minimum strain energy does not indicate a determinate value for θ)—

$$p_{\max.} = \frac{2E}{\sqrt{A}} \cdot \Delta$$

so that—

$$k = \frac{2E}{\sqrt{A}}$$

This would seem to show that k is not truly constant, but depends on the area of contact.

Yet another way of looking at it is to assume that when we have convex contact the area increases (and the stress diminishes) from $P/0$ ($= \infty$) until equilibrium is reached for a value of p a little above the elastic limit of the material. The writer does not

see how any simple rule can be deduced from this hypothesis unless we say simply—

$$\text{Area of contact} = \frac{\text{Load}}{\text{Elastic limiting stress for the weaker material.}}$$

This does not throw much light on the question of the shape and depression of the surface of contact.

$$\frac{2}{3} bl \times f_{\epsilon} = W$$

(The elastic limit must, of course be taken for the weaker material.)

Using formula (7)—

$$k = \frac{12 RmW}{bl^3}$$

and substituting for W we get—

$$k = \frac{8 Rm f_{\epsilon}}{l^2}$$

(This expression throws some doubt on the constancy of k .)

Thus, in the first numerical example on p. 183, if $f_{\epsilon} = 40,000$ lb.—

$$f_{\epsilon} \times \frac{2}{3} bl = 11,200$$

$$l = \frac{3 \times 11,200}{40,000 \times 1 \times 2} = \frac{3}{8} \text{ in. approximately.}$$

This differs from the experimental result, probably because f_{ϵ} is actually much higher than 40,000 lb. owing to continual restraining.

The elevation of the elastic limit in the case of wheels and rails probably proceeds until almost the ultimate stresses are reached, so that f_{ϵ} might even be as much as 80,000 lb., which halves the value of the length of the area of contact.

Presumably, too, if plasticity occurs the stress will become uniform over a considerable part of the surface of contact, and consequently the co-efficient $\frac{3}{2}$ should be reduced somewhat.

The Conditions of Equilibrium of a Cylinder and Plane when a force is applied parallel to the Plane sufficient to overcome the Resistance to Rolling.—Experiment shows that in most cases quite a small force or inclination of the plane to the horizontal overcomes the resistance. Before this occurs, however, there must be a tendency to slide in the direction of the applied force, which will call out a shear stress due to friction between the two pieces, and a slight compressive stress in front of the cylinder. If the applied force is increased, the resultant of it and the weight will become more and more inclined until it passes a point within the surface of contact beyond which the resultant of the stresses in the plane cannot pass. (That there is such a point is evident if we consider that an infinitely great stress needs to exist at the

Balance of Vertical Forces.

$$W = b \int p \cdot dx$$

Balance of Horizontal Forces.

$$P = b \int f \cdot dx \quad \dots \quad \dots \quad \dots \quad (10)$$

f is the horizontal component of the shearing stress* at any point. The resultant R_0 (= vector sum of P and W) must lie within the surface of contact, so that the *extreme* condition of balance is—

$$P(R - V) = \frac{Wl}{2}$$

$$\tan \phi_1 = \frac{l}{2(R - V)}$$

so that—

$$\tan \phi_1 < \frac{l}{2(R - V)}$$

The stresses over the surface of contact will now be somewhat as shown in the sketch below, where the resultant stress at each point is proportionate to the radial ordinate.

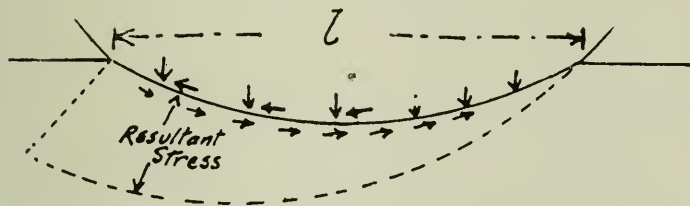


FIG. 6.

From this one may conclude that the usual statement that there can be no rolling resistance with mathematically geometrical and elastic materials is incorrect. The resistance is largely due to the continuous maintenance of a lateral compression and shear.

It is impossible to say exactly where the resultant of the stresses on the surface of contact acts, since the horizontal stresses are due to three causes—(1) lateral pressure, (2) lateral shearing accompanying the lateral pressure (3) shear owing to the expansion and relative motion due to the compression. The shear stress must depend, of course, on the compression, but as the full sliding resistance is not developed, there is no necessarily constant relation. Probably the resultant of the shears lies near to the plane containing the c.g. of the compressed segment

* In f must also be included the horizontal component of a bearing (i.e., compressive) stress caused by the lateral force.

between the surface of contact and the undisturbed surface of the rolling plane, while the resultant of the lateral pressure will be above this level. On the whole, therefore, we shall not be far wrong if we say that the resultant of all the horizontal stresses lies in a plane one third the depth of the depression below the surface.

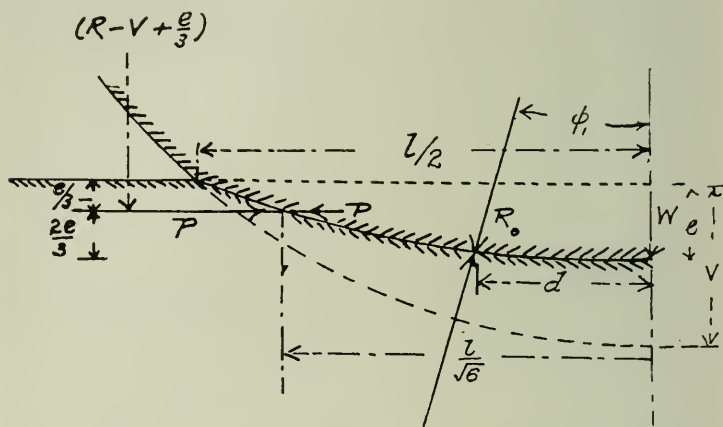


FIG. 7.

The applied torque is—

$$P \left(R - V + \frac{e}{3} \right) = W \cdot \tan \phi_1 \cdot \left(R - V + \frac{e}{3} \right)$$

the resisting torque is—

$$Wd = W \cdot (R - V + e) \cdot \sin \phi_1.$$

Hence—

$$\phi = \cos^{-1} \left(\frac{R - V + \frac{e}{3}}{R - V + e} \right)$$

since \$V = m e\$

$$\phi = \cos^{-1} \left(1 - \frac{2e}{3[R - (m - 1)e]} \right) \text{ or } \cos^{-1} \left(1 - \frac{2e}{3R} \right) \text{ approx.} \quad \dots \quad (11)$$

For example, the writer found that a steel roller 0.38in. dia. diminished 0.002in. under a pressure of \$\frac{1}{2}\$ ton (breadth 1.25in.). Hence \$e\$ is 0.001 (steel on steel dies in hydraulic press).

Hence \$\phi = \cos^{-1} (0.998) = \text{about } 3\frac{1}{2}^\circ \text{ or } 0.06 \text{ radian}\$ is the rolling angle for steel rollers on steel plates, the dia. of roller being 0.38in., and the pressure 0.4 ton per inch of breadth.

Resistance to Rolling on Non-Resilient Surfaces.—On common roads the surface materials have very little resilience compared with that of the wheel material, so that the effect of the passage of the wheel over the road is to cause a rut or groove in which the road material has acquired a set whose vertical depth is practically the same as the depression caused by the wheel when it was in the position considered. From this it follows that in every revolution the wheel strains a length $2\pi R$, and a breadth b , to a depth e , so that the work done in compressing the road is—

$$\frac{ke^2 2\pi Rb}{2}$$

The tractive force has during this time acted through a distance $2\pi R$, so that the resistance due to this cause is $kbe^2/2$.

As an example, if $k = 50$ lb. per inch of depth, and the wheels are 50ins. radius, the breadth being 5ins., and the total load 2,000 lb., the length of the surface of contact obtained from the previous equations is 8.4ins., the maximum compression is 0.7in., and the resistance to traction is $61\frac{1}{4}$ lb.

As the road surface becomes compressed so k will increase and e decrease, but probably at all times we can regard the road as being non-resilient, so that this rule will, if the resistance of the road surface to compression is known, serve for the estimation of the force required to draw a cart. It is obvious that the sliding resistances at the axle bear under many ordinary conditions quite a small ratio to the rolling resistance when the leverage of the wheel radius has been taken into account.

On asphalte and wooden roads there will, of course, be some resilience, and probably exact results can then be obtained only by dealing with the problem on the same lines as have been above suggested.

The Case of a Cone Rolling on a Cylinder.—In railway practice an important variation is made in the forms of the rolling pair. In order to provide lateral play and equality of resistance on curves the treads of the wheels are made conical and the rail has a cylindrical edge. In this case the surface of contact is not a rectangle, but a closed curve, which we may assume to be elliptical. Part of the weight by reason of the slope of the cone, is supported by a lateral compression and shear. The maximum depression of the rail or wheel occurs somewhere near the centre of the surface of contact, and the depression diminishes from this in every direction. Seeing that the area of contact is necessarily less than that of a cylindrical wheel on a plane, the co-efficient of rolling resistance will be a little greater if the whole weight is taken into account. The maximum strain and stress will also bear a smaller ratio to the mean.

The same general principles are, however, applicable, as the following notes will show. It is unfortunately almost impossible to separate the rolling resistances from the axle resistances in the case of ordinary rolling stock, but the writer's observations with a pair of wheels and axle rolling on a level track indicate about 2 or 3 lb. per ton as the usual rolling resistance with medium (40in.) sized wheels. This would indicate, on the basis of the preceding reasoning as to the position of the centre of pressure, that the length of contact does not often exceed one-tenth of an inch.

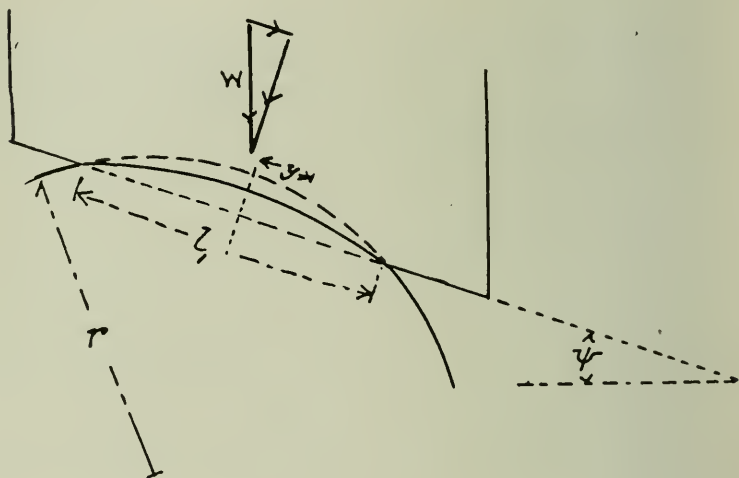


FIG. 8.

CONE AND CYLINDER ROLLING PAIR.

R = radius of cone at centre of contact area.

r = radius of cylinder. ψ = Cone angle.

l = length of contact. l_1 = breadth of contact.

$W \cos \psi$ = total normal pressure on contact area.

$W \sin \psi$ = lateral shearing force on contact area.

e = maximum compression of cylinder.

e_1 = " " cone.

$$e + e_1 = V = r \left[1 - \cos \left(\sin^{-1} \frac{l_1}{2r} \right) \right] = R \left[1 - \cos \left(\sin^{-1} \frac{l}{2R} \right) \right]$$

$$= r - \sqrt{r^2 - \frac{l_1^2}{4}} = R - \sqrt{R^2 - \frac{l^2}{4}} \quad \dots \quad (12)$$

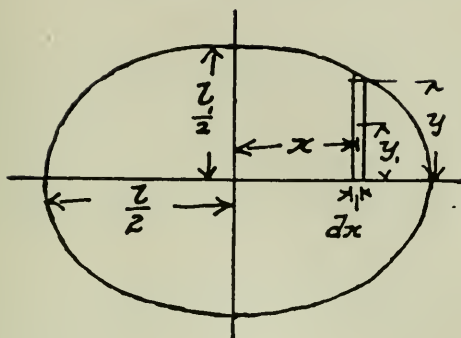


FIG. 9.

Assuming the contact area to be elliptic, we have—

$$\frac{x^2}{\frac{l^2}{4}} + \frac{y^2}{\frac{l_1^2}{4}} = 1, \quad \text{or} \quad y = \frac{l_1}{2} \sqrt{1 - \frac{4x^2}{l^2}}$$

Writing as before—

$$p = ke_{xy}$$

where e_{xy} means the compression of the cylinder at any point x, y , within the contact area.

$$W \cos \psi = \int p \cdot dA = \int \int ke_{xy} \cdot dy \cdot dx$$

Assuming a parabolic variation of strain—

$$e_{xy_1} = e_{\max} \left(1 - \frac{4x^2}{l^2}\right) \left(1 - \frac{y_1^2}{y^2}\right)$$

and—

$$W \cos \psi = 4ke_{\max} \int_{x=0}^{x=\frac{l}{2}} \left(1 - \frac{4x^2}{l^2}\right) \left[\int_{y_1=0}^{y_1=y} \left(1 - \frac{y_1^2}{y^2}\right) dy_1 \right] dx \quad \dots (13)$$

This simplifies to—

$$\frac{4ke_{\max}l}{3} \int_{x=0}^{x=\frac{l}{2}} \left(1 - \frac{4x^2}{l^2}\right)^{\frac{3}{2}} dx$$

In the integral—

$$\int \left(1 - \frac{4x^2}{l^2}\right)^{\frac{3}{2}} dx$$

let—

$$\frac{2x}{l} = z, \text{ then } dx = \frac{l}{2} \cdot dz$$

and—

$$z = \sin \theta$$

$$dz = \cos \theta \cdot d\theta$$

$$\left(1 - \frac{4x^2}{l^2}\right) = (1 - z^2) = (1 - \sin^2 \theta) = \cos^2 \theta$$

$$\left(1 - \frac{4x^2}{l^2}\right)^{\frac{3}{2}} = \cos^3 \theta$$

$$\int \left(1 - \frac{4x^2}{l^2}\right)^{\frac{3}{2}} \cdot dx = \frac{l}{2} \int \cos^3 \theta \cdot \cos \theta \cdot d\theta = \frac{l}{2} \int \cos^4 \theta \cdot d\theta$$

$$= \frac{l}{2} \left[\frac{\sin \theta \cdot \cos^3 \theta}{4} + \frac{3}{16} \sin 2\theta + \frac{3}{8} \theta \right]$$

The definite integral then is—

$$\theta = \sin^{-1} (1)$$

$$W \cos \psi = \frac{2ke_{\max} l l}{3} \left[\frac{\sin \theta \cdot \cos^3 \theta}{4} + \frac{3}{16} \sin 2\theta + \frac{3}{8} \theta \right]$$

$$\theta = \sin^{-1} (0)$$

since $\sin^{-1} (1) = \frac{\pi}{2}$, the expression in the brackets is—

$$\frac{\sin \left(\frac{\pi}{2}\right) \cdot \cos^3 \left(\frac{\pi}{2}\right)}{4} + \frac{3}{16} \sin (\pi) + \frac{3}{8} \cdot \frac{\pi}{2}$$

$$= \frac{3\pi}{16}$$

$$W = \frac{\pi ke_{\max} l l}{8 \cos \psi} \quad \dots \quad (14)$$

The mean pressure is—

$$\frac{W \cos \psi}{\pi \left(\frac{l_1}{2} \cdot \frac{l}{2}\right)} \quad \dots \quad (15)$$

and—

$$ke_{\max} = 2 \times \text{mean pressure.}$$

Equation (14) is similar in form to (1), (1A) or (1B), and the analysis proceeds on the lines previously indicated.

EXPERIMENTAL EVIDENCE.

The published experimental work on this subject is surprisingly meagre considering the importance of its practical applications. Coulomb pointed out that the moment required to overcome resistance to rolling depended on the forward displacement of the centre of pressure on the surface of contact, but does not seem to have observed that this displacement is itself a function of the radius of the roller (*Encyclopædia Britannica*, Vol. XV. p. 768).

He is quoted as having found the values of 0·006 and 0·004 for oak-oak and lignum-vitæ-oak pairs respectively, these numbers being the displacements in feet for rollers of unit radius. For other radii they must be divided by the radius in feet to obtain the ratio of the resistance to the weight.

In a paper which appears in the *Proceedings of the Institution of Civil Engineers*, Vol. CXIX. p. 456, some figures are given as the resistances to the relative motion of metal plates separated by metal rollers, and a formula as follows is deduced :—

Resistance in lb. = $c \times$ weight applied in lb./sq. root of radius (ins.)

c varies with the materials, and is as below for the three common forms of iron :—

Material of Rollers.			Materials of Plates.		
			Cast Iron.	Steel.	Wrought Iron.
Cast Iron	..	..	0·0063	0·0055	0·0070
Steel	..	..	0·0073	0·0064	0·0082
Wrought Iron	..		0·0120	0·0105	0·0135

The evident dependence of the constant on the elasticity of the materials is seen if the numerical order is studied, but this series of tests overlooks several points, *e.g.*, the breadth of the rollers.

In view of the difficulty of measuring accurately the small forces needed to overcome the resistances and the uncertainty of the variation of individuals from the mean when double plates and rollers are used, the writer procured a number of steel fly wheels mounted on spindles, the latter being made of various sizes. These were placed on a pair of very rigidly supported brass rails, the frame thereof being fitted with levelling screws. By accurately levelling the rails and then raising one end by the screws the rolling angles were determined, and in addition to this the mean rolling resistance was determined by the time occupied

by the travel of the rollers along a length of 3 ft. Numerous trials were made by the writer and his students, of which the following figures are the means :—

No.	Diameter of Spindle. Ins.	Weight of Roller. lb.	Weight per Unit Breadth of Contact. lb.	Rolling Angle. Radian.
1	0.25	16.00	39.02	0.0159
2	0.34	4.73	11.53	0.0168
3	0.50	16.25	39.63	0.0043
4	0.75	16.50	40.24	0.0038
5	1.00	17.00	41.46	0.0037
6	1.25	17.51	42.68	0.0035
7	1.50	18.02	43.90	0.0032

The effect of the breadth (it would be better called length) is seen by the discontinuity of the decrease in the rolling angle at No. 2. It will also be observed that these figures do not indicate that the rolling angle varies inversely either as the radius of the roller or as its square.

Some further figures, obtained by the writer with rollers (simple cylinders) on inclined planes show the effects of varying the breadth and the material.

No.		Diameter ins.	Weight. lb.	Weight per unit Breadth. of contact.	Rolling Angle. Radian.
8	Oak plane	0.372	0.11 (steel)	0.035	0.0093
9		0.372	0.07 do.	0.035	0.0093
10		1.5	1.35 (hard brass)	0.62	0.0053
11		0.761	0.04 (hard wood)	0.013	0.0070
12	as 8 but on glass plane		—	—	0.0058
13	as 9	Do. do.	—	—	0.0058
14	as 10	Do. do.	—	—	0.0035
15	as 11	Do. do.	—	—	0.0055

The following results were obtained with larger diameters on cast iron and pine (varnished) surfaces :—

No.	Diameter. ins.	Breadth of Bearing. ins.	Weight. lb.	Weight per Unit Breadth: lb.	Rolling Angle. Radian.
<i>On Cast Iron.</i>					
16	7.75	0.5	4.73	9.46	0.0016
17	6.0	1.0	7.75	7.75	0.0024
18	6.0	1.5	16.00	10.66	0.0012
19	6.0	1.5	16.25	10.83	0.0015
20	6.0	1.5	16.50	11.00	0.0020
21	6.0	1.5	17.00	11.33	0.0020
22	6.0	1.5	17.51	11.67	0.0018
23	6.0	1.5	18.02	12.01	0.0020

On Cast Iron, the Surface of the Roller Vaseline'd.

24	7.75	0.5	4.73	9.46	0.0024
25	6.0	1.5	16.00	10.66	0.0032
26	6.0	1.5	16.25	10.83	0.0035

On Pine Wood, Clean Surfaces.

27	6.0	1.0	7.75	7.75	0.0069
28	6.0	1.0	18.02	9.01	0.0061

Several points are noteworthy throughout the experiments :—

(a) The smallest flaw on the surface of the roller, or a particle of grit on the plane will increase the rolling angle by 100% or more.

(b) Greasiness of the roller or plane increases the rolling angle. This may be explained by the force necessary to overcome the cohesion or surface tension.

(c) At small linear speeds the rolling angle diminishes with the speed, and the starting value of the angle of rolling is appreciably more than the kinetic, but by an uncertain amount.

The value of k for cast iron, calculated by means of equations (8) and (11) from the results of experiments (18) to (23), is 3.0×10^9 , which compares well with the previous values of k for steel. These would indicate that k (the imaginary stress which would

cause unit strain in the rolling surface) is upwards of 200 times the modulus of elasticity E . A computation of the rolling angles under the conditions of the various experiments shows very fair agreement, but it is desirable that the value of k should be determined from a much more extensive series of experiments, for which the writer has not the apparatus.

RAIL PLATEWAYS. G. NOBLE FELL.

JOURNAL OF THE SOCIETY OF ENGINEERS (INCORPORATED),
July, 1912.



SNAEFFELL RAILWAY, ISLE OF MAN. View of permanent way, shewing centre rail.

RAIL PLATEWAYS.

By G. NOBLE FELL, A.M.INST.C.E.

ONE of the problems still to be solved by the railway engineer is to devise a means of quick, easy and economical transport, whereby the large areas of production at present without railway facilities may be brought into direct communication with existing railways and with the various market centres, so that not only would home products be able to compete successfully with those from abroad, but products which by reason of their small commercial value cannot bear the present cost of transport, could find a profitable and ready market. The railway companies will tell you that they can deliver foreign goods to our inland towns at lower rates than they are obliged to charge on home goods for half the distance ; the reason being that the foreign produce is focused, so to speak, at one point—the port of shipment—there to be collected at fixed times, thus ensuring a steady traffic with little or no break of bulk, whereas the home trade is intermittent and generally in small quantities, requiring special handling, and consequently being more expensive to deal with.

The rail is undoubtedly the cheapest means of land transport, but on account of the heavy first cost of construction, and the necessarily expensive method of working, our railways do not and never can secure benefits proportionate to the capital outlay. Mr. E. A. Pratt, in his *History of Inland Transport*, says :—

“ In regard to the possibility of an increase in railway rates, to enable the companies to meet increase in wages or other betterment of the position of their staffs, any general increase might well occasion uneasiness and even alarm to traders, who already find it difficult enough to meet foreign competition, and to whom greater cost of transport might be a matter of no little concern.”

When one realises the fact that the enormous sum of *One thousand three hundred and eighteen million pounds sterling* has been spent on the construction of railways in the United Kingdom, requiring an annual income of 76 millions to work them and a further sum of 46 millions to provide interest at the modest rate of 3½ per cent. on invested capital, one begins to think that in these days of invention and progress some means should be devised for relieving the producer, the consumer, and the public alike, of at least a portion of this heavy burden.

The most perfected means of mechanical road traction cannot compete with railways for long distance carriage, although in

many cases, this mode of transport possesses advantages over railways, especially in hilly countries, where the latter are more or less confined to the valleys. What is required is an intermediate system, combining the merits of the railway with the facilities afforded by the highway, that is, economic transport coupled with rapid and easy means of collection and distribution.

Some years ago, the late Mr. Alfred Holt, of Liverpool, and a number of gentlemen interested in the trade of Lancashire and Yorkshire, grasped the idea that if the raw material could be conveyed from the ship direct to the mill, and the manufactured article from the mill to the market, a large saving might be effected in the cost of production. These gentlemen applied themselves to the task of solving this problem, and devised a plan whereby road wagons and lorries could be run over a plateway worked by mechanical means. Unfortunately their efforts were not successful, owing to the heavy expenditure involved in the method devised, estimated at no less than £48,000 per mile of plateway. One can readily understand that at this figure no great saving could be effected over carriage by rail, seeing that the adjacent railways, the London & North Western, and the Lancashire and Yorkshire, had cost on an average £53,400 and £67,800 a mile, respectively. One further realises another fact, which is that every ton of goods carried over these roads must, besides paying its way, be charged also with its proportion of interest on this heavy capital outlay.

In speaking of plateways, Mr. Holt said "Even with public company obligations, if managed as prudently as these obligations permit, and when successful in lowering charges rather than aiming at extensions, they (the plateways) will in a few years take their place amongst the best of the carrying companies, resting on the broad and safe basis of supplying a great and permanent want in the best manner known in the present state of invention."

The author firmly believes with Mr. Holt, that the plateway has a great future, and will come to stay when once practically installed. Two elements, however, are absolutely essential, that is, economy in construction, and the power to follow closely the configuration of the ground so as to extend its scope beyond the capabilities of the ordinary railway. The ideal of the plateway is that it shall enable any and every desired point to be reached, and thus be the means of collecting and distributing traffic with the least possible delay at the lowest possible cost.

A plateway pure and simple, that is, a track laid along the public highway to facilitate the passage of ordinary vehicles, is a failure in this respect, and does not meet the requirements of the case. What is necessary is the application on such a track of the best means of propulsion (whether steam, petrol or electric)

to work the traffic economically and expeditiously. To do this we must first of all remove the track from the public road, and place it on its own acquired ground. A public road is not the place for such a plateway or railway. Next we must provide a suitable permanent way, that will carry a locomotive, a railway wagon, and a road vehicle. This is quite practicable as will be seen by reference to Figs. 1, 2, and 3 (Plate I.), which show a special form of plateway rail, "*a*" being the space provided for the flanged wheels of the railway stock, and *b* the space on the same rail allotted to the wheels of the road vehicles. The gauge adopted is 4ft. 8½ins. so as to allow of the circulation of ordinary railway wagons over the plateway, and it is proposed to carry road vehicles of a width not exceeding 5ft. 6ins. over the wheel tracks (that is, the measurement from outside to outside of the wheels at ground level), the intention, however, being to construct suitable road wagons for working on the plateway and so to avoid the expense of altering existing wagons to suit railway traction, in such matters as couplings, draw-bars, brakes, &c.

The specially designed rails are laid on a longitudinal foundation formed of concrete, or timber and concrete combined, to which they are securely fastened by means of spikes and bolts. This form of support, or road bed, does away with the ordinary cross sleepers and ballast, and constitutes a solid track, giving a continuous bearing, and enabling a lighter form of rail to be used than would otherwise be possible. The original broad gauge permanent way of the Great Western Railway, as designed by Brunel, was laid with bridge rails, carried on longitudinal timbers, laid flat instead of upright, which method may also be adopted on these plateways, under certain circumstances. The two bearing rails are braced together at intervals by light steel cross ties, whereby the gauge of the line is kept in perfect adjustment.

A further departure from the ordinary methods of railway construction is the adoption of a third or centre rail, which is used to assist traction on steep inclines. The cross-tie above mentioned is so constructed as to form a chair, raised slightly above the carrying rails. The tie is secured to longitudinal beams, and supports the centre rail, upon which run horizontal wheels. These wheels on the locomotive are worked by a separate pair of cylinders, and are made to grip the rail by means of elliptic springs, compressed by the action of a right and left handed screw, thus giving the engine the additional adhesion necessary for overcoming steep gradients. Horizontal wheels with flanges running under the head of the centre rail may also be attached to the wagons and carriages, to guide them round sharp curves, and to make it impossible for a vehicle to leave the track when descending a hill.

Gradients up to 1 in 10 have been successfully worked for many years by this system, and there is no reason why steeper gradients than this should not be overcome, especially where electric traction is adopted. The centre rail is used also for brake purposes, the brake acting directly on the two faces of the rail, giving absolute safety on steep inclines.

This brake is operated by a powerful screw working two parallel arms which carry the brake blocks, and practically constitutes a vice gripping the centre rail. It can be worked by hand, or automatically. In the latter case, should a coupling break, the train would be brought to an immediate standstill, even on the steepest incline. With the above system the author has travelled down gradients of 1 in 10, at a speed of 40 miles an hour, with perfect safety. Naturally on level ground the centre rail is not required, and the engine is worked by the two outside cylinders and carrying wheels alone, and when an incline is reached the driver, by putting the horizontal wheels into motion, can take the train up the hill as easily as it had travelled on the level. No change of engine, nor even change of gear is necessary, the mere opening of a regulator giving the extra power required. Fig. 4 shows these engines working on the Rimutaka incline in New Zealand, where the system was adopted by the Government for getting over the high ground separating Wellington and Masterton. The saving in cost as compared with a railway of ordinary construction, was estimated at over £100,000.

In laying out railways or plateways, the radius of the curves enters largely into the question of economy in construction, for if it is possible to contour closely the sides of the hills, a very great saving can be effected in the quantity of earthwork, and in the extent of land to be purchased. It is the rigid wheel-base of the locomotive which governs in the first place the radius of the curves, and secondly the speed of the trains, although where the centre rail is laid this latter element is not of great importance. In designing plateways these two elements have been considered, with the result that the limit of 5 chains radius is considered advisable under all ordinary conditions, although in particular cases a 3-chain curve may be practicable with special arrangements. With a gauge of 3ft. 6ins. even 2 chain curves have been worked successfully. It is proposed to limit the speed to 15 miles an hour on the level, and to 10 m.h. up, and 15 m.h. down the steep inclines, although the author feels confident that these speeds may be safely exceeded.

A special form of level crossing has been devised for roads, where the centre rail is laid, and means are provided whereby the road vehicles can be removed from the track when required to resume their journey by road, or vice versâ. This is done by tapering the longitudinal guard rails in the direction of the line, so as to form an incline, up which the wheels of the vehicles

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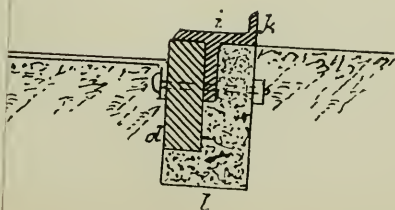
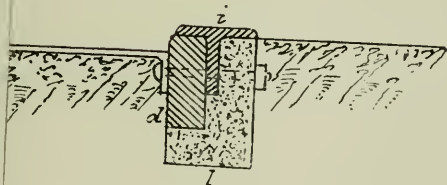
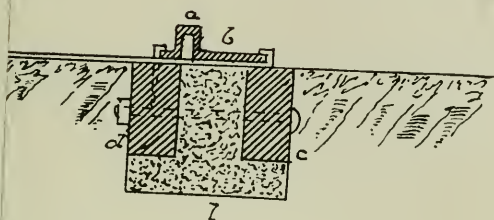


Fig. 1.

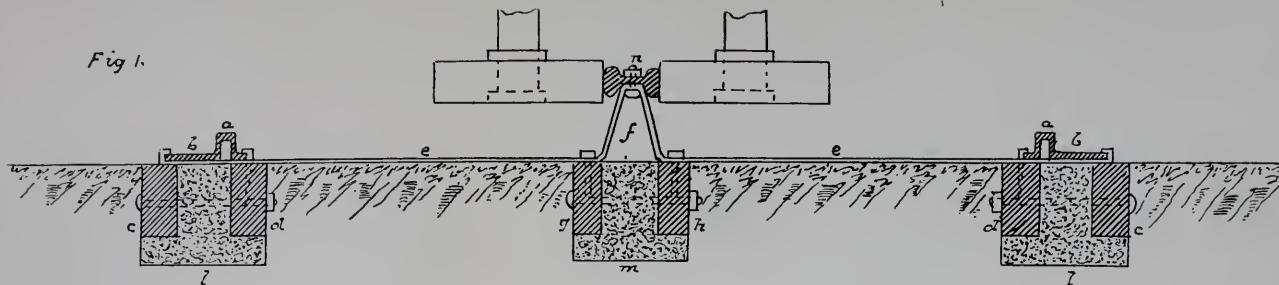


Fig. 2.

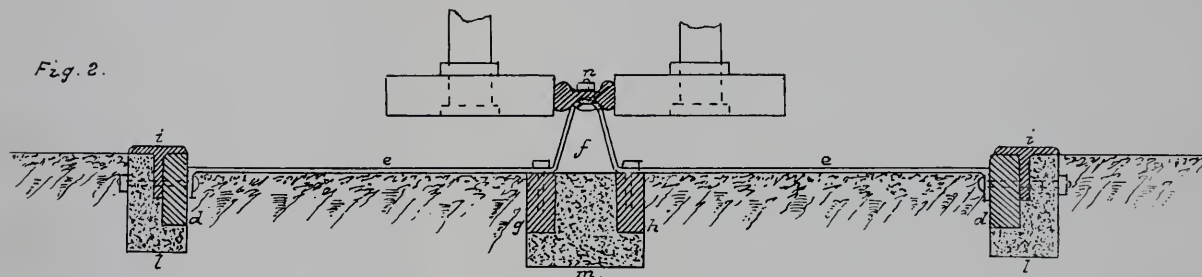
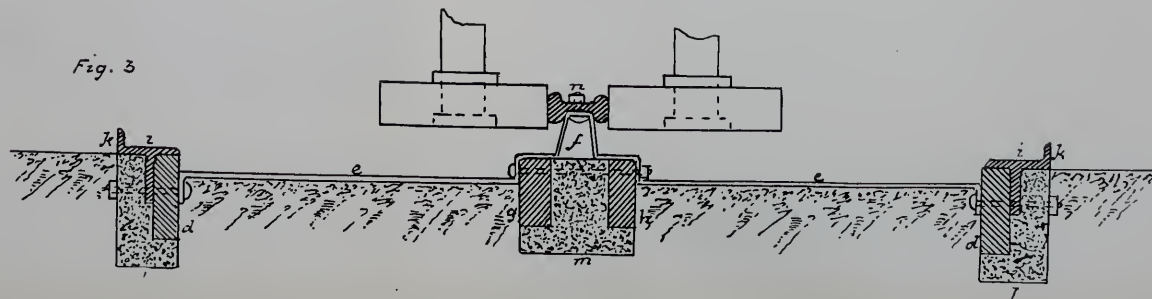


Fig. 3



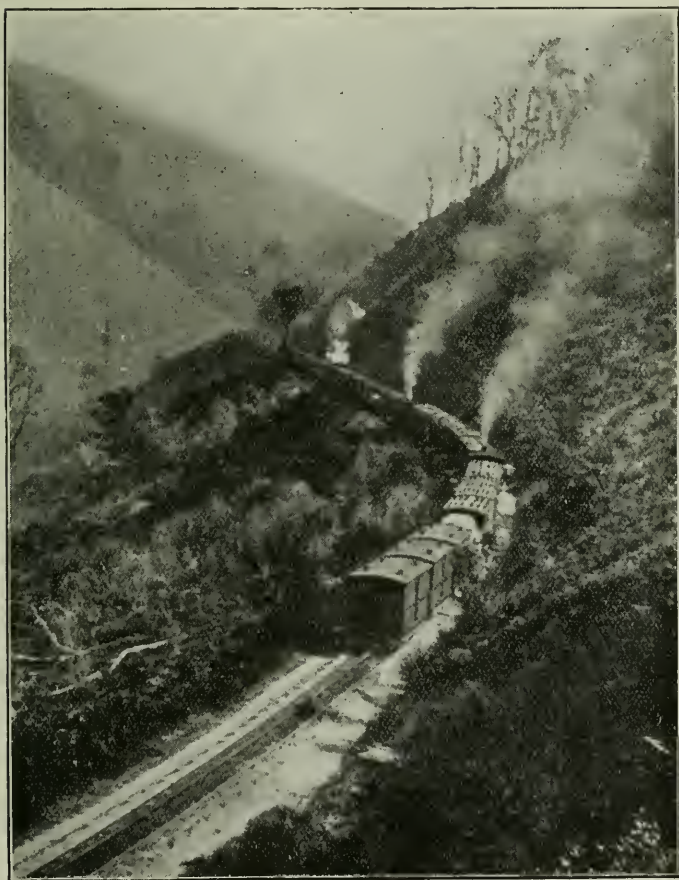


FIG. 4. NEW ZEALAND GOVERNMENT RAILWAYS.

View of train drawn by "Fell" engines on Rimutaka Incline.
Gauge, 3 ft. 6 ins. ; Grade, 1 in 15, with numerous 5-chain curves ;
Weight of train, exclusive of engines, 260 tons.

can be drawn to the level of the roadway. The same means will apply to stations, and to other points where it is desired to rail or derail road vehicles, thus giving agriculturists, manufacturers, mine owners and others, advantages such as are not and never have been possible with the present form of railway construction.

It may here be noted that plateways are not intended to and cannot compete with existing railways; they are to become feeders, and to constitute a means of bringing traffic to them, and distributing traffic for them, in a more expeditious and economical manner than has hitherto been possible. They will form an intermediate means of transport, and will perform what neither the railway nor the highway is capable of doing, that is, they will combine the special functions of both.

In order to keep the cost of construction as low as possible, and so to bring these plateways within the means of every district not possessing railway accommodation, the axle loads will be limited to 5 tons, that is to say, a 10-wheeled locomotive not exceeding 25 tons in weight, will be sufficiently powerful to deal with the class of traffic to be carried, and will be capable of working on the gradients above mentioned. As the gauge of 4ft. 8½ins. will be adopted, the ordinary light stock of the existing railways will be able to run over the plateways, and transhipment of freight will thus be avoided. There is no reason why road motors (steam, electric or petrol) should not utilise the plateway, and it will be a matter for experiment whether, in some cases, the traffic could not be carried to greater advantage by motors with rubber tyred wheels, than by ordinary locomotives.

Several types of plateway have been studied, that shewn in Fig. 1 (Plate I.) being designed to carry locomotives up to 25 tons weight, and ordinary railway trucks weighing 10 tons loaded, or bogie trucks weighing 6 tons each and carrying a load of 14 tons. This type is laid with two specially rolled steel rails, *a*, *b*, weighing 50lb. per lineal yard, carried on the longitudinal timbers *c* *d*, to which they are spiked in the usual manner. These beams are in their turn carried on, and bolted to, concrete foundations, the upper surfaces of which correspond with the ground level. The two rails are braced together by the steel tie-bar *e*, whereby the gauge of the line is kept in proper adjustment. On steep inclines this tie-bar also serves the purpose of supporting the centre rail, as it forms a chair (shown at *f*), to which the rail is bolted and fished in the usual manner. This chair is carried on, and secured to, two longitudinal beams *g* *h*, laid in concrete, and the whole permanent way is thus framed together in a very solid manner. This form of permanent way, including the centre rail and foundations, is estimated to cost

£1,300 per mile, calculating labour and materials at average present day prices.

Taking as an example a mile of plateway, carried along the side of a hill, with say an inclination of 1 in 10 (1 in 40 would represent the gradient upon which an ordinary railway would be constructed) over moderate ground, that is, calculating upon an average depth of bank and cutting of 5ft., and an average width of 24ft. of land required or about 3 acres to the mile, we have the following cost :—

COST OF ONE MILE OF CENTRE RAIL PLATEWAY.

<i>Single line.</i>	<i>Gauge 4ft. 8½ins.</i>
	£
1. Land. Average price £50 per acre ..	150
2. Earthwork. Average cost 1s. 3d. per cu. yd. ..	515
3. Bridges and Culverts	500
4. Permanent way, Fig. 1, including sidings ..	1,445
5. Stations	250
6. Fencing. Double for the whole distance ..	260
7. Level crossings	100
8. Telegraph	80
	£3,300
Contingencies, 10%	330
	£3,630
Rolling stock	750
Legal expenses, administration, engineering, and interest during construction	620
Total cost of construction and equipment ..	<u>£5,000</u>

A plateway constructed on this system over a hilly country and capable of hauling traffic up inclines of 1 in 10, may therefore be built for £5,000 a mile. The cost of an ordinary railway, over similar ground, would be from £10,000 to £15,000 a mile, besides the cost of the extra length of line that would be required for reaching the same altitude with a 1 in 40 grade.

Having found the cost of the plateway, let us see what will be its carrying capacity. Take a line 20 miles in length, divided into three sections, and suppose that there is a length of 5 miles at each end with gradients of 1 in 10, and that the intervening

portion is undulating country with normal grades, which would represent a line rising from sea level to a plateau at an elevation of 2,640 feet, and falling again to sea level, that is, a line connecting two valleys separated by a broad range of hills. At speeds of 15 m.h. on the level, and only 8 m.h. up, and 15 m.h. down the inclines, the journey can be made in 1 hour 35 mins., and by running the engine a double trip on the first incline, so as to give a full load for the rest of the journey, the round trip can be made in 5 hours, allowing ample time for shunting, coaling, &c. A centre rail engine of 25 tons weight will take behind it a gross load of 49 tons up a grade of 1 in 10, or a net paying load of 28 tons; the net double load will therefore be 56 tons, and one engine could make 3 round trips in 15 hours, carrying a total net load of 336 tons. With 4 engines running therefore, 1,344 tons may be carried in a day, or a total paying load of 403,200 tons in 300 working days. By increasing the amount of rolling stock, the capacity of the line may be proportionately increased, passing places being provided at suitable distances. The foregoing will give an idea of the utility of a plateway even under such exceptional circumstances, and if such a line can bring an increase of even a hundred thousand tons of traffic a year to an existing railway it will be looked upon as a valuable feeder.

Instead of a double headed rail, an H or channel bar may be used as a centre rail where the traffic is light. The carrying rails may also be formed of T bars, as shewn at *i* (Fig 2). With this form however, it will be necessary to provide a flange *k* (Fig. 3) for keeping wheels of the road vehicles on the track where the centre rail is not laid. The cost per mile of this type of permanent way, including the centre rail, is £920, and the estimated cost of one mile of plateway is £3,750 over a hilly country and £2,500 a mile on fairly level ground.

As already stated, road motors could make use of the plateway under certain conditions, and a further development in this method of transport might be made by adapting it to military purposes. A lightly constructed line, closely contouring the sides of the hills, and running over, instead of tunnelling through them, could be constructed very expeditiously over broken country, by utilising a special form of trestle bridge, already in use, for spanning water-courses, as shewn in Fig. 6, or for crossing exceptionally rough ground; and a rapid means of communication could be opened up between the base of an army in the field, and say the nearest railway, or from the base to some point which it was necessary to hold. Not only could stores and ammunition be carried in the railway trucks, but the ordinary military ammunition and store wagons themselves might be run over the plateway, and at any point along the route they could be taken off and proceed to their destination by road. In case of need, say where roads did not exist, or were



FIG. 5. VIADUCT ON TORRINGTON AND MARLAND RAILWAY.

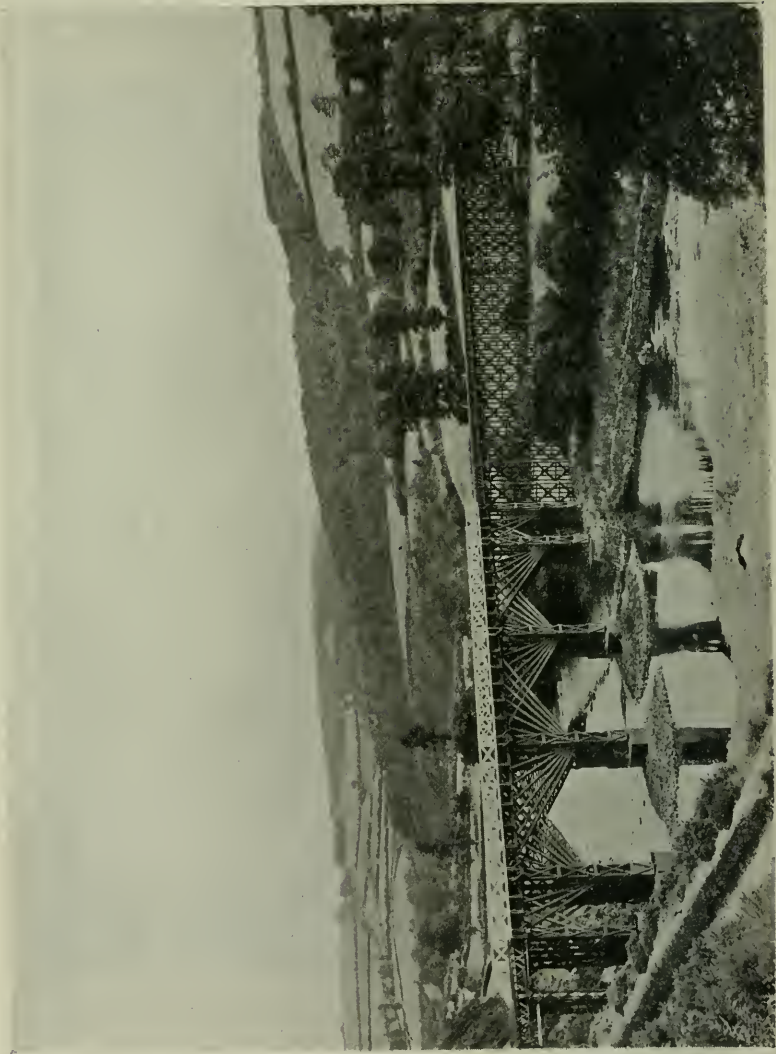


FIG. 6. TORRIDGE BRIDGE AND VIADUCT, TORRINGTON AND MARLAND RAILWAY.

badly constructed, horses could make use of the plateway, and there would be no difficulty in moving field artillery in this way, thus greatly facilitating movements of troops from one point to another. For temporary work the concrete foundations could be dispensed with, and rough broken stone could be used for securing the longitudinal beams or sleepers in position, and so expediting construction. Every single piece of material would be made as light as possible, so as to be easily handled in the field, in fact no piece should exceed the weight of a mule pack, although where practicable the line should be made to carry its own materials.

Some years ago a series of trials, in which the author took part, were made by the War Office at Aldershot with a light form of portable field railway. These trials extended over a period of several months, and the results were reported by the Royal Engineer Committee to be highly satisfactory. The trial line was rather over a mile in length, two-thirds being laid with curves ranging from 3 to 7 chains radius. The gauge was 18 inches, and although the weight of the locomotive was only $4\frac{1}{2}$ tons, it was capable of hauling loads of from 25 to 30 tons up a gradient of 1 in 50. As a result of these experiments the conclusion was reached that, "Railways made on this principle were well adapted for carrying all kinds of military stores as well as siege guns and ammunition, and that they could be constructed with much greater rapidity than any other form of railway in use."

Another example of a light railway of this description, where light timber viaducts were substituted for heavy banks and cuttings, is the Torrington and Marland Railway, in North Devon, mentioned in Mr. Vernon-Harcourt's work on Railway Construction. It is 8 miles in length, the gauge being 3ft., and although there are many viaducts of from 20 to 25 feet in height, such as that shewn in Fig. 5, and a bridge over the River Torridge, of three 45ft. spans, and 40ft. high (Fig. 6), the total cost of construction was only £20,000, or at the rate of £2,500 a mile. It was opened in 1880, and is still carrying a heavy mineral traffic. It is intended to utilise similar light viaducts either in timber or steel for the system of plateways now proposed, in order to secure economy and rapidity of construction, and this method, combined with plateways and the centre rail system of traction, will be an entirely new departure in railway building, which should give results that have hitherto neither been attempted nor anticipated, but which come within the limits of practical engineering.

The following table gives the cost of working the Torrington and Marland Light Railway, for the year ending

31st December, 1911. The cost of management is not included in these figures.

Locomotive Account.

	£	s.	d.	£	s.	d.
Coal	396	13	8			
Oil waste, packing, etc. ..	120	2	6			
Repairs and renewals ..	382	15	10			
				£899	12	0

Track Account.

Rails	194	11	2			
Viaducts	61	3	11			
Sleepers	36	16	6			
				292	11	7

Wages Account.

Platelayers, drivers, stokers, &c.	1,231	4	11
	£2,423	8	6

Less cost of transfer to and from own trucks to L. & S.W. Railway, at Tarring-

ton Station	430	9	0
Distributing and collecting traffic	234	18	0

665 7 0

Actual cost of working £1,758 1 6

£1,758 1s. 6d. ÷ 35,326 tons = 11·97d. (say 1/-) per ton.
1/- per ton for 8 miles = 1½d. per ton-mile.

THE MODULUS OF ELASTICITY OF THIN FLEXIBLE STRIPS.

By PROF. F. H. HUMMEL, M.Sc., A.M.INST.C.E.

[MEMBER OF COUNCIL.]

THE modulus of elasticity (Young's modulus) of a material can be determined, directly, by applying tension or compression to the specimen and measuring the elastic deformations by means of an extensometer. When the necessary apparatus is not available for this test, or the form of the specimen is not suitable, the modulus can be determined by a bending test. In this test the specimen is supported as a beam, loads are applied (usually in the middle of the beam), and the elastic deflections measured. These deflections must be small compared with the length of the beam for two reasons :—

(1) In order that, with specimens of the form and dimensions usually employed in such a test, the elastic limit of the material shall not be exceeded.

(2) In order that the formula $\delta = Wl^3/48EI$. connecting the deflection and the modulus may be applied without error, that is, without transgressing the assumptions made in deriving the formula. If, however, the specimen is very flexible, it may give large deflections under small loads, or even under its own weight, and the formula quoted above cannot be applied. We can proceed to find the modulus of elasticity of such a strip by loading it as a beam (the most convenient practical way will be indicated later), but the slopes and deflections of the loaded beam will be large, and it will be necessary to investigate some simple properties of an elastic strip, greatly bent, in order to obtain a formula by which the modulus of elasticity can be calculated.

Elastic Curves.—The forms taken by elastic strips loaded in various ways are called elastic curves. These curves have been studied by many elasticians. The determination of the equation to the curve of the deflected strip leads to mathematical difficulties in the form of elliptic integrals, and only one or two of the simplest cases have been analysed. On this account the properties of such elastic curves are not usually considered in text books for engineers, but only simple cases where the deflections are small are given.

Some important properties of elastic curves can be easily established and expressed in formulæ as simple as those in use for small deformations, and cases may arise (as in the problem under consideration, of finding the value of the modulus of elasticity) where they are useful. All classes of elastic curves are of interest, but only one kind need be considered here, the strip loaded as a beam. The case considered will be that of a strip clamped in a

horizontal direction at one end and bent under its own weight and a load at the free end, in the manner of a cantilever. Such an arrangement is equivalent to the half of a beam supported at the ends and loaded in the middle.

Fundamental Equation.—The equation on which all problems on bending depends is the one connecting bending moment and curvature, $M=EI/R$, derived in all text books of applied mechanics.

M is the bending moment.

E the modulus of elasticity.

I the moment of inertia of the cross-section.

R the radius of curvature.

This equation holds at all sections of a bent beam, provided the stresses and strains due to the bending moments are very large compared with the direct or shearing stresses at all sections. So long as this condition is satisfied it does not matter how much the beam is bent, if the stresses at no place exceed the elastic limit of the material.

The equation $M=EI/R$ cannot be applied to a stiff rigid thing, such as a chain link, as the deformations in such a case may be due as much to the tensile and shearing stresses as to the bending. The insignificance of the shearing and direct stresses in a very thin strip can be seen numerically by considering a steel strip $0.02 \text{ in.} \times 0.25 \text{ in.}$ and 10 in. long fixed as a cantilever, which will be bent nearly through a right angle by a load of 0.1 lb. hanging at the end. In this case the maximum direct stress and the maximum shearing stress are each about 20 lb. per square inch, whereas the bending stress amounts to $40,000 \text{ lb.}$ per square

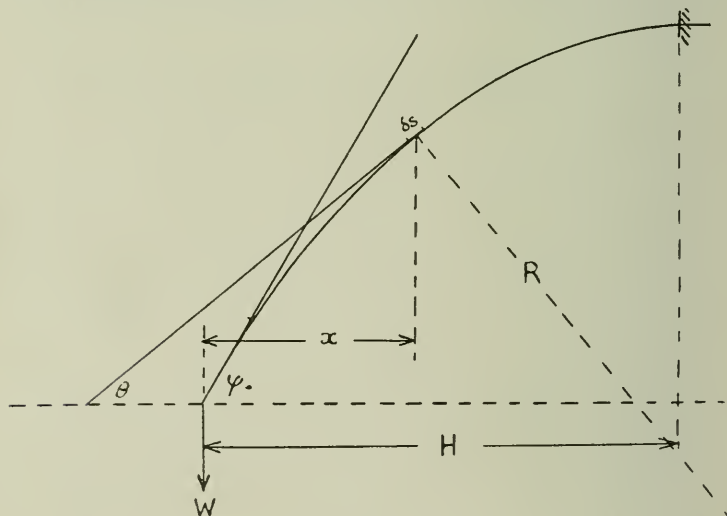


FIG. 1.

inch. Practically speaking, the relation $M=EI/R$ holds for all beams originally straight, however much bent, so long as the elastic limit stress is not exceeded. In all ordinary stiff beams this condition involves very small deflections, but if the beam is thin and therefore flexible, the deflections may be large.

Derivation of Expression for the Slope of a Bent Beam.—Only one case need be considered, that of a cantilever, which for the present may be considered loaded in any way. Fig. 1 shows the deflected strip of uniform cross-section; a single load at the end is shown, but any system of loads can be imagined which determines the bending moment at each point.

If ds is a small length of the curve and $d\theta$ the angle between the tangents drawn at each end of it—

$$\frac{d\theta}{ds} \text{ is the curvature} = \frac{1}{R} \quad \dots \quad (1)$$

R being the radius of curvature.

For each point on the curve we have—

$$\frac{d\theta}{ds} = -\frac{1}{R} \quad \dots \quad (2)$$

$$\text{Now } M = \frac{EI}{R} \quad \therefore \quad d\theta = -\frac{M}{EI} ds \quad \dots \quad (3)$$

In the beam theory for small deflections θ may be assumed equal to $\tan \theta$, and ds to dx , and equation (3) becomes—

$$d \tan \theta = -\frac{M}{EI} dx, \text{ and by integrating—}$$

$$\tan \theta = -\frac{1}{EI} \int M dx \quad \dots \quad (3a)$$

If M can be found as a function of x , an expression for the slope at each point is found, and hence by a second integration the equation to the deflected beam.

In the case under consideration no such assumptions can be made. We have, however—

$$\frac{dx}{ds} = \cos \theta,$$

and equation (3) becomes—

$$\cos \theta d\theta = -\frac{M}{EI} dx,$$

and by integration—

$$\sin \theta = -\frac{1}{EI} \int M dx \quad \dots \quad (4)$$

It will be noticed that this equation (which applies to all beams, however much curved), is of exactly the same form as the equation (3a), which is limited to small deflections. The integra-

tion of $\int M dx$ is exactly equal to $\sin \theta$, and therefore approximately to $\tan \theta$ if θ is small. With equation (4) we can proceed no further in attempting to find the equation to the curve, but the slope at any point can be found, if M , E , and I are known, or if the slope is known by measurement, E can be found knowing I and M . The curve can also be drawn with accuracy by a graphical construction depending upon the equation. Equation (4) is the only one that we need consider in developing the subject.

CASE I.—A strip with a single weight W at one end, and the weight of the strip itself neglected.

Referring to Fig. 1, the bending moment at any point $x = Wx$ equation (4) becomes—

$$\sin \theta = -\frac{1}{EI} \int Wx \, dx$$

$$\therefore \sin \theta = -\frac{W}{EI} \frac{x^2}{2} + c \quad \dots \quad \dots \quad \dots \quad \dots \quad (5)$$

where c is a constant of integration.

When $x=0$, $\theta=\psi$, the angle made by the tangent to the curve of the strip at its free end—

$$\therefore \sin \psi = c,$$

and (5) becomes—

$$\sin \psi - \sin \theta = \frac{W}{2EI} x^2 \quad \dots \quad \dots \quad \dots \quad \dots \quad (6)$$

$$\text{When } x=H \quad \theta=0,$$

and (6) becomes—

$$\sin \psi = \frac{W}{2EI} H^2 \quad \dots \quad \dots \quad \dots \quad \dots \quad (7)$$

Equation (7) enables E to be calculated if ψ and H are measured from the curve. The value of ψ can be measured quite accurately because the curve at the end is straight, and the tangent can be drawn with a straightedge placed close against the bent strip. H is a linear measurement. The thickness of the strip must be determined very accurately with a micrometer, for the correct calculation of the moment of inertia I . Equation (6) is easily checked experimentally by measuring a number of values of x and θ for a particular curve, and equation (7) by varying the value of W and measuring ψ and H . This matter will be referred to later after other cases have been investigated.

CASE II.—*An Unloaded Strip deflected by its own Weight.*—This case requires investigation for two reasons: (a) it may be necessary to experiment with strips so thin and flexible that, except for impracticable short lengths, they will not carry more than their own weight; (b) in Case I., just considered, if the experiment is made in the simplest way with the weight just hung on the end, the weight of the strip comes in as a correction factor.

This can be avoided by having the strip lying in a horizontal plane and pulling the end, but this arrangement elaborates the apparatus, and it would seem preferable to apply the correction factor, and to keep the apparatus of the simplest possible description.

Let Fig. 1 now represent a strip bending under its own weight. Equation (4) is true for the case, but the difficulty is to express M as a function of x . If w is the weight per inch of the strip, the weight of any small length dx , measured horizontally = $w \sec \theta \cdot dx$.

The bending moment will be the same at each point as on a horizontal beam with an intensity of load at each point of $w \sec \theta$. Thus, if an approximate expression can be found for $\sec \theta$, an intensity of load curve can be drawn, and the required bending moment found by integration by the usual method of applied mechanics.

The author has investigated a number of these curves, and finds the following equation for $\sec \theta$:—

$$\sec \theta = \frac{1 + \sec \psi}{2} + \frac{\sec \psi - 1}{2} \cos \frac{\pi}{H} x \quad \dots \quad \dots \quad \dots \quad (8)$$

TABLE I.
STEEL STRIP BENT UNDER ITS OWN WEIGHT.
 $\sec \psi = 2.05$. $H = 9.22$ ins.

x Inches.	$\frac{x}{H} 180^\circ$.	$\cos \frac{x}{H} 180^\circ$.	$\sec \theta$ Calculated.	θ Calculated.	θ Measured on curve.
0	0	1	2.05	60° 45'	60° 45'
1.22	23 7°	0.92	2.01	60° 0'	60° 30'
2.22	43.4°	0.73	1.91	58° 20'	58° 40'
3.22	62.9°	0.45	1.76	55° 30'	55° 20'
4.22	82.5°	0.13	1.59	51° 0'	50° 50'
5.22	102°	0.21	1.41	45° 0'	44° 55'
6.22	121.5°	0.52	1.25	36° 50'	35° 10'
7.22	141°	0.78	1.12	26° 30'	27° 50'
8.22	161°	0.95	1.03	14° 0'	15° 50'
9.22	180°	1.00	1.00	0°	0°

This is an empirical equation, but its accuracy can be seen in the foregoing table, which refers to a steel strip .006in. thick and 0.237in. wide. Values of x and θ were measured at a number of points on a tracing of the deflected strip, and $\sec \theta$ calculated from equation (8). It will be seen that the table refers to a strip having considerable deflection, the maximum slope being 60° .

Considering that the measured values of ψ were obtained by drawing tangents to the curve by eye, the agreements are quite satisfactory for practical purposes, and the differences are greatest at points near to the fixed end, where the effect on the bending moment is least.

Referring to equation (8) $w \sec \theta$ is the intensity of load, and $\int_0^x w \sec \theta \cdot d\theta$ is the shearing force, viz., the weight of the strip to any section x . This integration leads to the equation—

$$l = \frac{H}{2} (1 + \sec \psi) \quad \dots \quad (9)$$

where l is the length of the strip. This is given only as being an interesting property of the curves; it is not required in subsequent work.

Let $\int_0^x w \sec \theta \cdot dx = S$, then the bending moment at any point is $\int_0^x S \cdot dx$.

Having the expression for M , the bending moment, we have next to substitute it in equation (4) and omitting the mathematical steps, which are quite straightforward, we obtain—

$$\begin{aligned} \sin \psi &= \frac{w}{2EI} \left[(1 + \sec \psi) \frac{H^3}{6} + \frac{H^3}{\pi^2} (\sec \psi - 1) \right] \\ &= \frac{wH^3}{30EI} (1 + 4 \sec \psi) \quad \dots \quad (10) \end{aligned}$$

This is the equation for a strip under its own weight corresponding with equation (7) of Case I., and from it if ψ and H are measured, E can be calculated. If ψ is very small, $\sec \psi = 1$, and the formula reduces to $\psi = \frac{wH^3}{6EI}$ for a strip very slightly deflected.

The following table gives results of tests of such strips, in some cases the same strip tested under different conditions in order to compare results:—

TABLE II.

Modulus of elasticity of various materials from measurements of ψ and H of strips deflected by their own weight

Material.	Dimensions.	Weight per in. w .	Moment of Inertia of cross-section I.	H	ψ	Modulus of Elasticity.
Celluloid	Ins. $0.763 \times .0302$	lb. .00145	Ins. 1.75×10^{-6}	Ins. $\begin{Bmatrix} 10.62 \\ 11.05 \end{Bmatrix}$	$34^\circ 10'$ $51^\circ 15'$	lb. per sq. in. $344000 \}$ 347500 $351000 \}$
Celluloid	$1.00 \times .019$	.00128	5.71×10^{-7}	$\begin{Bmatrix} 8.56 \\ 9.18 \end{Bmatrix}$	$28^\circ 45'$ $42^\circ 45'$	$543000 \}$ 547000 $551000 \}$
Drawing paper in direction of rolling	$1.23 \times .0078$	3.1×10^{-4}	4.86×10^{-8}	$\begin{Bmatrix} 5.38 \\ 5.80 \end{Bmatrix}$	28° $53^\circ 30'$	$390000 \}$ 394000 $398000 \}$
Drawing paper across direction of rolling	$1.23 \times .0078$	3.1×10^{-4}	4.86×10^{-8}	$\begin{Bmatrix} 5.90 \\ 6.65 \end{Bmatrix}$	28° 44°	$575000 \}$ 581500 $588000 \}$
Thick stiff paper ..	$1.08 \times .0123$	5.47×10^{-4}	1.67×10^{-7}	$\begin{Bmatrix} 8.65 \\ 9.19 \end{Bmatrix}$	$27^\circ 20'$ $35^\circ 20'$	$846000 \}$ 852000 $858000 \}$

In Case I, equation (7) was obtained for a strip loaded at the end, but no numerical examples of its application were presented because, in most cases, the weight of the strip itself has to be included as a correction. It is possible to avoid the introduction of this correction by keeping the axes of the strip horizontal, and applying the load by a delicate spring balance or by a weight over a pulley. As it is an advantage to make the experimental apparatus as simple as possible, the author thinks that hanging a weight on the end of the strip and making the allowance for the weight of the strip is preferable.

CASE III.—*A Strip loaded at the end with a weight W, the weight of the Strip being allowed for.*—The form of the strip will be similar to that of one loaded merely by its own weight, and equation (8) will hold approximately. Note that if W is small and the correction for the weight of the strip important, then equation (8) applies most accurately; on the other hand, if W is large, no doubt equation (8) does not apply so well, but then it only comes in as a small, and in a number of cases, negligible, correction.

The total bending moment will be the sum of the separate bending moments, and $\sin \theta$ will be the sum of the integrals of the bending moments due to W and w separately; the expression for $\sin \psi$ is, therefore the sum of the expressions obtained in Case I. and Case II., viz. :—

$$\begin{aligned} \sin \psi &= \frac{W}{2EI} H^2 + \frac{wH^3}{30EI} (1 + 4 \sec \psi) \\ &= \frac{H^2}{EI} \left[W + \frac{wH}{15} (1 + 4 \sec \psi) \right] \quad \dots \quad \dots \quad (11) \end{aligned}$$

It will be seen that the effect of the weight of the strip is to increase W by the amount $\frac{wH}{15} (1 + 4 \sec \psi)$ and an idea of the importance of the correction in any particular case can be readily estimated assuming $\sec \psi$ to have a large value, say 1.5. The following tables give results of tests, E being calculated from equation (11).

Experiments 1 to 4 in Table III. refer to a strip of a definite length (12in.) loaded with different weights, and 4 to 8 refer to the same strip with varying lengths loaded with the same weight (0.221 lb.). The variation in the value of E over this wide range of experimental conditions is almost exactly 1%.

EXPERIMENTAL APPARATUS.

The experiment is of such an extremely simple nature that the apparatus hardly needs any description. A flat board fixed against a wall, or held vertically in some other way, with a brass angle screwed to it and levelled to form a horizontal fixed sup-

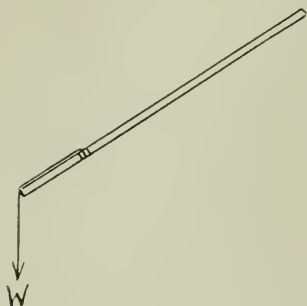
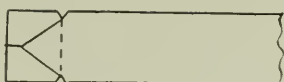


FIG. 2.

port on which the end of the strip can be held flat is all that is necessary. A reflecting glass scale, with its zero vertically below the edge of the fixed support, is the best means of measuring H , the weight being hung on to the end of the strip by a silk thread. The simplest way of attaching the silk to the strip is shown in Fig. 2. It is looped over the two side notches and hangs over the end of the strip. The notches may be very slight indeed. The angle ψ is measured by a protractor after the tangent to the end of the strip has been drawn on the paper with a straightedge adjusted by eye. The edge of the scale used for measuring H gives a convenient horizontal line for the measurement of ψ . In

the author's investigation of the curves assumed by a strip under its own weight the complete curve was wanted, and was obtained by fixing the board opposite a window, and printing the shadow of the strip on ferro-prussiate paper, but that is not necessary in the ordinary experiment for determining E . It is easy to notice if the strip has been overloaded and a permanent set introduced, by noting its unloaded position before and after the test.

NOTE ON ANTI-CLASTIC CURVATURE.

The modulus of elasticity obtained by a bending test is not the same as Young's modulus, obtained by direct tension or compression if the anti-clastic curvature is prevented. The anti-clastic curvature is the transverse curvature of the beam due to the decrease in width of the tension fibres and the increase in width of the compressed fibres, corresponding to the longitudinal lengthening and shortening respectively.

It is usually stated that for wide thin strips this transverse curvature cannot take place, but in some cases the curling of the edges is visible to the eye, and Table IV. does not indicate that the value of the modulus is affected by the ratio of width to thickness of the strip. There may be an effect, but it is small, and in cases where the strip in use is to be subjected to bending, and for purposes of comparing similar strips, the modulus found by the method described is satisfactory, and in any case, so far as the investigation has gone, differs very little from Young's modulus.

TABLE IV.

These tests were made on boxwood strips. A strip about lin. wide was cut into four strips of different widths, and the value of the modulus of elasticity found for each. The results indicate that the value of the modulus is not affected by the ratio of width to thickness within the range of the experiment.

Dimensions of strip.	Weight per in.	Moment of inertia of section.	W.	H.	Maximum slope ψ	Sec ψ .	Correction for weight of strip.	Sin ψ .	Modulus of elasticity.
Ins.	lb.	(Inch) ⁴ .	lb.	Ins.	26° 20'	1.116	lb.		lb. per sq. in.
0.770 × .0395	.000848	3.94×10^{-6}	$\begin{cases} .0441 \\ .0882 \\ .1323 \\ .1764 \end{cases}$	11.33	26° 20'	1.116	.00348	0.444	175,000
				10.15	43° 55'	1.388	.00375	0.693	173,000
				9.05	56° 30'	1.812	.0042	0.834	171,000
				8.15	63° 40'	2.254	.0046	0.896	172,000
0.248 × .0385	.000266	1.18×10^{-6}	$\begin{cases} .011 \\ .022 \\ .033 \end{cases}$	11.48	23° 15'	1.088	.00109	0.395	172,000
				10.50	39° 10'	1.290	.00115	0.631	172,000
				9.50	50° 15'	1.563	.00122	0.769	171,000
.093 × .038	.000098	4.27×10^{-7}	$\begin{cases} .0044 \\ .0066 \\ .0110 \end{cases}$	11.42	25° 55'	1.112	.00040	0.437	167,000
				10.90	35° 15'	1.224	.00042	0.577	169,000
				9.87	49° 15'	1.532	.00046	0.757	173,000
.051 × .039	.000055	2.52×10^{-7}	$\begin{cases} .0022 \\ .0044 \\ .0066 \end{cases}$	11.59	21° 25'	1.074	.00023	0.365	176,000
				10.70	37° 35'	1.261	.00024	0.610	172,000
				9.74	49° 30'	1.540	.00026	0.760	174,000

Mean 172,100

NOTE ON THE METHOD OF DRAWING THE DEFLECTION CURVE OF BEAMS.

A method very often employed for drawing the curved form of a loaded beam is to divide the bending moment diagram into strips, and substitute for each strip a force proportional to its area acting through the centre of gravity of the strip. The link polygon for this set of forces represents to scale the form of the deflected beam, under the action of the given bending moments, provided the actual deflections are extremely small. The modification of this method when the deflections are large is as follows :—

In the above manner the bending moment diagram AGJ (Fig. 3) is drawn to any convenient scale and sub-divided into strips represented by the forces ab, bc, cd , etc. In this case AG is not the length of the beam (a cantilever fixed at G), but the horizontal projection of it called H in the preceding work. The forces ab, bc , etc., are set down to form a vector polygon ag to any scale. The pole O is chosen so that the angle aOg equals ψ , that is, $\sin \psi = \frac{ag}{Oa}$ and by equation (4).

$$\sin \psi = \frac{\text{Total area of B.M. curve (inches)}^2 \text{ (lb.)}}{E \text{ (lb. per sq. in.) } I \text{ (inches)}^4}.$$

so that the curve refers to a perfectly definite strip.

Arc ag' is now drawn with O as centre, and the points a, b, c , etc., projected to $g', c' — g'$ on the arc. If a link polygon $A' G'$ is drawn with sides parallel to rays Oa, Ob', Oc' , etc., instead of Oa, Ob, Oc , etc., the curve obtained is the deflected form of the strip, whatever the magnitudes of the deflections may be. It will be noticed that if ψ is very small the arc ag' will nearly coincide with ag , and the construction becomes the usual one for small deflections.

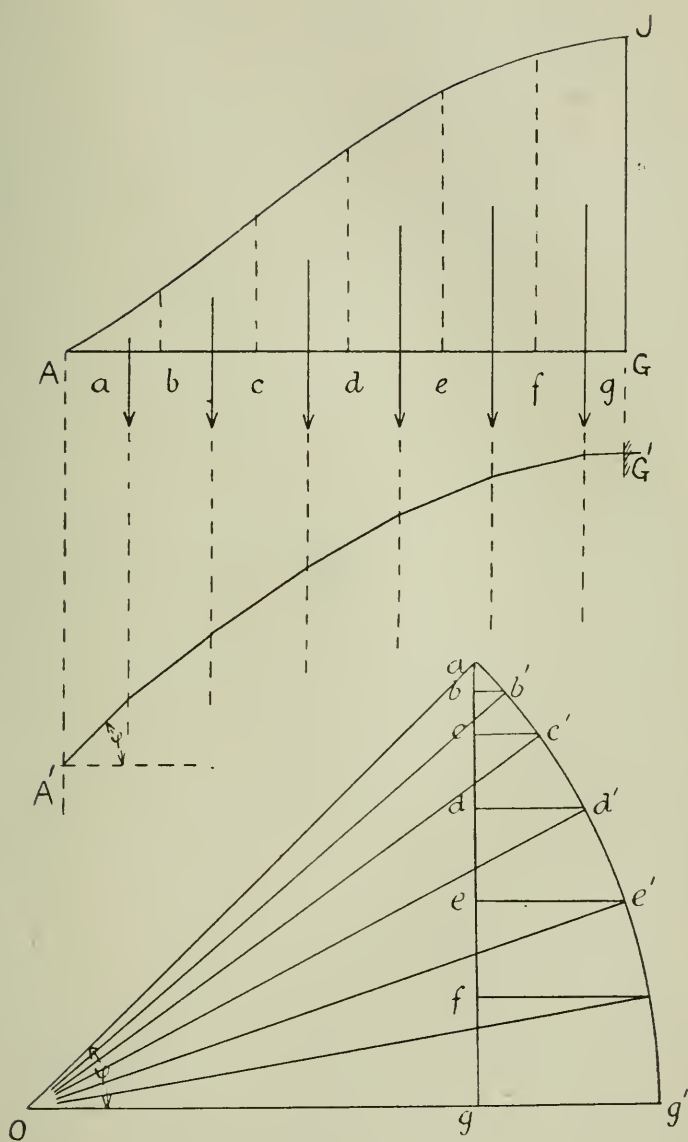


FIG. 3.

TABLE V.

This is a table of a few miscellaneous materials, experimented upon by the method described.

Material.	Dimensions.	w lb.	W	H	ψ	Modulus of elasticity.
Celluloid, A.	ins. 0.763 × .0302	per in. .00145	lb. .0110	ins. 7.73	64° 36'	lb. per sq. in. 349,000 349,000
Celluloid, B.1.	0.768 × .062	.00264 {	.0441 .0882 .1105	10.81 9.48 8.90	33° 10' 49° 55' 56° 25'	390,000 } 390,000 } 390,000 }
Celluloid, B.2.	2.254 × .062	.00087 {	.0110 .0220	11.19 10.16	28° 10' 44° 5'	385,000 } 384,000 }
Whalebone	0.300 × .044	.00061 {	.0441 .0662	5.73 5.11	44° 5' 55° 30'	504,000 } 502,000 }
Copper	0.233 × .014	negligible	0.1105	2.80	30° 55'	15,900,000 15,900,000
Brass	0.237 × .0208	"	0.3310	2.66	34° 45'	11,600,000 11,600,000
Aluminium, nickel, alloy	1.17 × .036	.00417	0.3305	10.46	24° 40'	10,000,000 10,000,000

THE CONSTRUCTION OF A LONDON COUNTY COUNCIL LOW LEVEL MAIN SEWER FROM BATTERSEA TO DEPTFORD.

By J. P. HARRIS, M.Inst.C.E.

As part of a general scheme for dealing with the main drainage system of the Metropolis, the carrying out of which has extended over a considerable number of years, a new low level sewer was constructed from Battersea to Deptford, and this work forms the subject of the following paper.

The sewer commenced at the junction with an existing sewer at North Side, Wandsworth Common, in the Borough of Battersea, and terminated at the L.C.C. Deptford pumping station in the Borough of Greenwich, where the sewage, when the sewer is in operation, will be pumped into the low-level outfall sewers leading to the Crossness Outfall Station. The route traversed is shewn on Figure 1 (page 224).

The work carried out included the construction, in tunnel, of about 3 miles of brick sewer from 6ft. to 6ft. 6in. in diameter, and of nearly five miles of cast-iron sewer varying in diameter from 7ft. 6in. to 8ft., together with connecting sewers, cast-iron working shafts, penstock chambers, and junctions with sewers already in use.

The point at which the portion constructed in brickwork was to end, and the cast-iron part to begin, was determined by the level of the subsoil water, it having been decided to adhere to the brickwork section where no water had to be contended with, but to adopt the cast-iron section (constructed with the aid of compressed air) where water was present, and as the two methods of construction are totally different, the method adopted for the construction of the brickwork portion will be described first.

Brickwork Portion.—Three working shafts were excavated on this portion, sufficiently large in area to be converted, at a later date, into permanent side entrances into the sewer. These shafts were some 3,500ft. apart and of an average depth of 56ft. They were timbered in the usual manner, practically no subsoil water being met with, and, in all three cases, from the bottom of the shaft to a considerable height above the level of the top of the sewer, the ground was of blue clay.

Excavation for the construction of the sewer was begun from the bottom of the shafts, in both directions, so that each shaft served two working faces. The work was so arranged

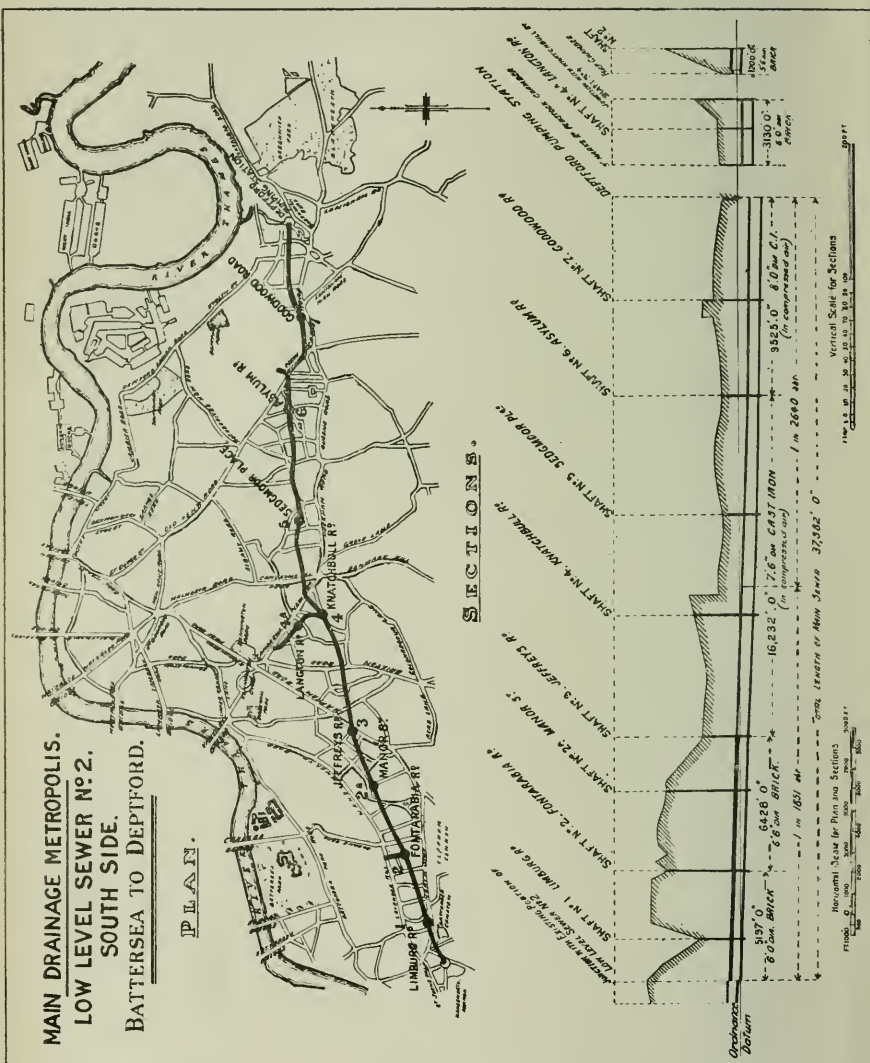


FIG. 1.—PLAN AND SECTION OF LOW LEVEL SEWER.

that the miners worked at night, and the bricklayers in the day-time, the former getting out sufficient ground to enable the latter to complete a length of sewer of 7ft. 8in. a day, or 46ft. a week. Work was carried on simultaneously at all three shafts, so that, under favourable circumstances, a length of 276ft. of completed sewer was constructed in a week. The brick portion of the sewer, as previously mentioned, varied in diameter from 6ft. to 6ft. 6in. (see Fig. 2), and was constructed of three rings of brickwork, the inner or sheeting ring being of pressed bricks (the lower half of Staffordshire blue bricks), while the two outer rings were of red wire-cut bricks.

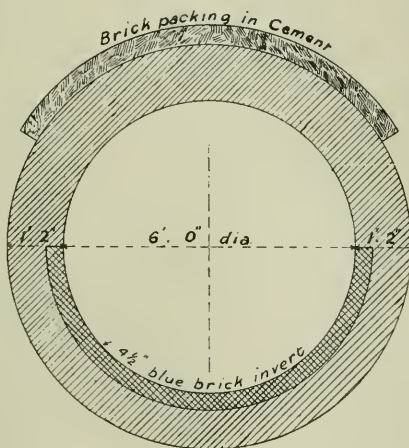


FIG. 2.—SECTION OF BRICK SEWER.

Scale $\frac{1}{4}$ " = 1 foot.

In excavating for a 7ft. 8in. length, five timber crown bars, 7in. in diameter, were used, the leading ends being supported on props and the back ends on the second ring of brickwork of the length of sewer previously completed. These crown bars held up the $1\frac{1}{4}$ in. poling boards, which were spaced several inches apart, the ground tunnelled through being blue clay not requiring close timbering. A small timbered heading about 12ft. in length, was kept in advance. As the brickwork was built up the crown bars and poling boards were removed and the spaces occupied by them, which were not taken up by the third ring of brickwork, were filled in with rough brick packing in cement mortar. By this method the amount of timber left in permanently was reduced to a minimum. An excavated length standing on timber is shewn on Fig. 3 (overleaf).

As an extra precaution against leaving any cavities above the completed work, in places where the sewer passed under railways and other important properties, short pieces of iron pipe were built into the crown of the sewer, at short distances apart, and cement grout forced in under pressure.

As previously stated, each working shaft served two tunnel faces, and owing to the somewhat restricted area allowed for a working shaft (which was, in each case, in a public street) careful arrangements had to be made to utilise, as far as possible, all available space within the hoarding erected to enclose the site, the extent of which had to meet with the approval of the local authorities in whose borough the site happened to be.

The usual arrangement was as follows:—The hoarding was erected enclosing a space some 140ft. long by 25ft. wide, with the shaft about equidistant from either end. One end of the enclosed space was used for the storing of materials, mixing mortar, etc., and the other end was occupied by the muck stage, on to which, by means of an electric crane erected alongside the shaft, the excavated material was dumped, and then let fall through trap doors into carts which were backed in under the stage. All the materials were lowered and all the “excavation” raised by means of the electric crane, and a ladder was fixed in each shaft for the use of the workmen.

From the bottom of the shaft to each working face rails were laid on sleepers, the “road” being extended periodically as the working faces advanced, and the skips were pushed in and out by boys. The tunnels were lighted by electric light and the working faces supplied with fresh air by means of a pipe leading from an electric air-pump fitted in the shaft. At intervals along the sewer, at distances of about 800ft., permanent side entrances and ventilating shafts were constructed, the former to give access to the sewer, throughout the whole length of which a galvanised iron chain was fixed as a safeguard for the flushers when working in the sewer.

Cast-Iron Portion.—There were four shafts on this portion, three of which were used as working shafts from which the cast-iron length of the sewer was constructed. They were all circular in shape, consisting of cast-iron rings, varying in diameter from 17ft. to 20ft. according to the permanent use to which they were to be put. With the exception of the bottom ring, the shaft rings were 4ft. in depth, each ring being made up of 12 segments. The bottom ring was 2ft. in depth, having a cutting edge for sinking purposes, and the two rings immediately above this one had special castings to form “eyes” in the shaft for the sewer to pass through. Above the eyes an air-tight floor designed to withstand an upward air pressure of $11\frac{1}{2}$ lb. per sq. in., was fixed, constructed of girders and floor plates.

The method of sinking a shaft was as follows :—The ground being excavated for a few feet in depth from the surface, to the shape required, *i.e.* :—a circle having a diameter of 17ft. or 20ft. as the case necessitated, the cutting edge or bottom ring was erected. Excavation was then proceeded with inside the ring and under the cutting edge, and, as the ring gradually sank, the second ring was added, and bolted to the first, and so on until the cutting edge had reached the depth at which water was met with. Work was then suspended until such time as the air-tight floor and the air lock were erected in position.

Excavation was then proceeded with under compressed air, additional rings being erected on top as the cutting edge sank deeper. To assist the sinking of the shaft the air-tight floor was loaded with cast-iron tunnel segments. When the cutting edge had passed through the water-bearing strata and was well embedded in the blue clay underlying the ballast, the clay was trimmed and a level bottom formed inside the shaft. A layer of Portland cement concrete, 2ft. in thickness, was then deposited all over the bottom, and the joints between all the segments of the shaft were caulked with lead wire and rust cement, a groove having been cast in the segments for that purpose. The compressed air was then taken off and a portion of the air-tight floor removed to allow of the shields for driving the tunnels being lowered, in parts, to the bottom of the shaft. This having been done the air-tight floor was made whole once more, and preparations were made to proceed with the construction of the cast-iron sewer.

Only one air-lock was provided at each working shaft for both materials and men, and was situated above ground. On the air-tight floor a vertical air shaft was erected, circular in shape, and 6ft. 3in. in diameter, from which the horizontal air lock was constructed. The height from the air-tight floor of the shaft to the floor of the lock was about 30ft. and to the top of the air shaft (which was finished off in the shape of a dome) about 50ft. Inside this dome an electric motor was fixed for dealing with all materials to be lowered for the construction of the sewer.

The horizontal air-lock was 6ft. 3in. in diameter, with a length between the doors of 10ft. 6in., and was fitted with all necessary air-cocks, pressure gauges, etc. The air-lock and air-shaft were designed to withstand a working air pressure of 20lb. per sq. in. As before mentioned there were three working shafts on the cast-iron portion of the sewer, and the above description of the air-lock, etc., together with the following description of driving the shields from the bottom of the shafts, are common to all three.

On the completion of the air-lock arrangements, and the erection of the tunnel shields at the bottom of the shaft, com-

pressed air was once more employed, and the temporary plugs, which had filled the sewer "eyes" of the shaft while the latter was being sunk, were removed, and excavation, with the help of the shields, was commenced in either direction from the shaft for the construction of the sewer. The shields, of which there were six working at one time, were of the ordinary type, being 9ft. 2in. in length, and having eight rams, each of 7in. in diam., with a stroke of 1ft. 10in. The top half of the cutting edge projected 1ft. 6in. beyond the bottom half, thus forming a "hood." (See Plate I.)

The pressure for working the shields was obtained by taking water from the ordinary water mains in the streets and leading it to a Hayward-Tyler air-driven hydraulic pump mounted on a tank on wheels. The air cylinder of this pump was double acting and 7in. in diameter, the ends of the 1in. piston rod forming the plungers for the hydraulic force pumps. The air was admitted to the air cylinder at a pressure of about 60lb. per sq. in., the hydraulic pressure being transmitted from the force pump to the shield rams at about 2,940lb. per sq. in.

The cast-iron portion of the sewer, about 26,200 ft. in length, consisted of cast-iron rings, $\frac{7}{8}$ in. of an inch in thickness, lined with Portland cement concrete, mixed in the proportion of 2 parts of granite chippings, one part of sand, and one part of cement; the invert, and the sides of the sewer up to axis level, being faced with pressed blue bricks. Each ring was made up of six segments and a key piece with internal flanges, 6in. deep by $1\frac{1}{4}$ in. wide, with $\frac{7}{8}$ in. stiffeners, and measuring 21in. in length (see Plate II.). To ensure water-tightness the flanges of all segments were machined, except for a space 1in. in depth on the inside, where the iron was $\frac{1}{8}$ in. less in thickness than the remainder of the flange. When two segments were bolted together there was, therefore, a space 1in. deep by $\frac{1}{4}$ in. wide, forming a groove which was afterwards caulked with lead wire and with iron filings and sal-ammonic, the latter making an efficient rust joint. The bolt holes were made water-tight by fitting yarn grummets well soaked in red lead under the iron washers which were used on the bolts at each end. (See Plate II.)

The greater part of this cast-iron portion of the sewer was constructed through water-bearing gravel and sand, and under compressed air. The method of working was as follows:—The face of the tunnel was well covered with pug or puddled clay, close boarded and strutted, to prevent falls of the soil, and (as far as possible) the escape of the compressed air. A portion of the ballast and sand from opposite, and nearly all round, the cutting edge of the shield was taken out in "pockets" about 18in. wide by 24in. deep, extending to about 3in. outside the circumference of the cutting edge of the shield. As these "pockets"

were excavated they were filled with pug or clay, well rammed in, until, almost for the complete circumference of the cutting edge, there was a face of clay instead of the original gravel.

As the shield advanced, the cutting edge passed over the timbered face and penetrated the clay, a "blanket" of which was left outside the skin of the shield, thus preventing to a great extent any escape of air at the tail. The hydraulic rams which actuated the shield, obtained a bearing against wood packing, placed between them and the last cast-iron ring erected, and pushed the shield forward into the face, sufficiently far to enable one tunnel ring to be put in under cover of the shield. Before this ring was put in, however, the previously erected one was "grouted up," the annular space between the outside of the iron and the ground surrounding it being filled with liquid lime grout, forced in under a pressure of about 60lb. per sq. in., through the holes left in the cast-iron ring segments for that purpose, each hole being afterwards filled with a screw plug fitted with a yarn grummet.

The hydraulic rams were then drawn into their cylinders and the next ring erected. This being done, the face of the tunnel was once more attacked, the horizontal face boards being taken down, two at a time, and on the ground being excavated, put into their fresh position 21in. further ahead, and temporarily strutted from the shield until such time as the whole of the face was advanced. "Soldiers," or upright timbers, were then erected, bearing against all the face boards and were strutted back to a completed tunnel ring, the temporary struts being then knocked out and the shield pushed forward once more over the timbered face (see Plate I.). Good progress was made by this method of working, the ordinary rate of progress being 7 rings of completed tunnel segments, erected in 24 hours, or a length of nearly 86ft. in a week.

On the completion of the cast-iron tunnel, and after the caulking of all the joints between the segments had been done, the compressed air was let out of the tunnel, and any joints or bolt holes that showed any sign of water, due to leakage, were made good. The tunnel was then thoroughly cleaned out and a commencement made with the concrete lining.

In the lining of the cast-iron sewers the bottom half was completed first. The flanges of the iron rings were filled with concrete, up to axis level of the sewer, and faced with Staffordshire blue bricks. The arch was then proceeded with, centreing being erected for a length of 36 tunnel rings, or 63ft., at a time. The laggings were of the box type, 15ft. 9in. in length by 12in. in width, and 4 sets were needed to complete a "length." Five laggings were used on either side in each set and block laggings in the top for the "key." The first lagging on either side was fixed in position at axis level, and the concrete deposited in

the space between the laggings and the skin of the iron rings, and thoroughly punned in to ensure the rings being well filled. The second laggings were then erected, similar concreting done, and so on until the whole of the arch was completed with the exception of the key. The block laggings were then fixed in position and the "keying in" executed. On the completion of a length the concrete was allowed to stand undisturbed for 24 hours before the centreing was removed.

The whole of the plant for the cast-iron tunnel portion of the work was worked electrically, and the materials were hauled along the tunnels by an 8 h.p. electric locomotive. The tunnels were lighted by electric light, and telephonic communication was available between the men working in compressed air, and those at the shafts outside the air-lock. Air compressing plant was installed at all three working shafts, and comprised the following at each shaft, viz:—Two high-pressure and six low-pressure machines, constructed by Reavell & Co., of Ipswich, all driven by two-phase motors. The high-pressure machines had four cylinders, each 8 in. diam., with a 7 in. stroke, and were run at a speed of 280 revs. per minute, maintaining an air-pressure of 80 lb. per sq. in., in the receiver, to feed the grouting machine and hydraulic pump for working the shield. They were belt-driven and were fitted with an automatic belt-shifting device, and all usual fittings.

The six low-pressure machines were fitted with hand unloading valves on three of the cylinders, to enable one or more to be cut out, if required. They were all run at a speed of 300 revs. per minute, and were capable of compressing a total quantity of 3,000 cubic feet of free air per minute to a pressure of 15 lb. per sq. in. In addition to the above, an Ingersoll-Rand compressor was added, at one of the shafts, capable of compressing 2,637 cubic feet of free air per minute to a pressure of 15 lb. per sq. in. Each plant was fitted with two pairs of after coolers for cooling the air before it was supplied to the tunnels.

During the time the building of the main sewer was being carried out several connecting sewers were also being constructed, the longest of these being over 3,000 feet in length. These were to connect the new sewer with an existing low-level sewer, and at the junctions of the two, penstock chambers were built and cast-iron penstocks were erected to control the flow of sewage. In building the penstock chambers over the existing sewer some difficulty was experienced, the flow of sewage in this sewer having to be maintained, and, although the normal flow is only 3 ft. in depth, in times of storm the sewer is liable to be surcharged.

The diameter of the sewer is 7ft. 3 in. and in order to construct the penstock chamber a length of 24ft. had to be cut away entirely. After several schemes had been considered it was decided to cut away the top half of the sewer, and choosing a fine night when the flow of sewage would be comparatively small, to construct a temporary length of iron sewer, long enough to span the portion cut away, and to project into the brick sewer at either end. For this purpose some of the iron air-shaft, previously used in connection with the air-lock, came in most conveniently, being in sections of suitable length with external flanges for bolting the sections together, and 6ft. 3in. in diameter. In carrying out the work these sections of iron pipe were lowered on to the brick invert of the existing sewer (the sewage having been dammed back temporarily), fixed into position, and the spaces at either end between the outside of the iron pipe and the inside of the brick sewer built up in brickwork. The sewage then flowed through the iron pipe, which allowed sufficient space underneath to cut away the bottom half of the brick sewer and to construct the floor of the penstock chamber. After the chamber had been completed to above the level of the sewer the iron pipe was removed and the sewage allowed to flow through its new and permanent channel.

Setting out.—It is not intended to go very fully into the question of the setting out of these works, as the subject of setting out for underground tunnels has been dealt with in great detail in the description of the tube railways constructed during the last few years, but owing to the fact that this sewer passed almost entirely under private property, and did not, as was the case of the tube railways, keep as much as possible under streets, the setting out required a considerable amount of care, and a very large traverse survey had to be made, the extent of which will be understood when it is stated that above the ground alone some 90 angles, and some 100 lines had to be measured. The angles were measured with an 8in. theodolite, furnished with micrometers, capable of reading to 5 seconds, and the lines with a 100ft. steel tape correct at a temperature of 44 deg. Fahr. The measured lines were corrected for any difference in temperature at the time of taking the measurements, and also for any variation in the level of the surface of the ground, readings being taken with a level, and the measured distance being reduced to the true horizontal distance. Satisfactory results were obtained at the junctions of the tunnels, the error in no case being more than half an inch in either line or level, although some of the "drives" were of considerable length, one in particular being over 6,100ft., which the author believes is the longest tunnel constructed from one face executed in London up to the present time.

Gradients.—The gradients of the main sewer are 1 in 1851 and 1 in 2640, and the depth from the surface of the ground at which the sewer was constructed varied from about 22ft. to about 70ft.

Quantities.—The amount of brickwork used in the brickwork portion of the sewers, including side entrances, etc., was about 27,500 cubic yards, and the weight of cast-iron in the cast-iron portion, including penstock chambers, etc. was 22,200 tons. The work was carried out by Messrs. Griffiths & Co. (Contractors), Ltd., of London Wall, E.C., at a cost of about £450,000.

Work was commenced in January, 1910, and has taken nearly 3 years to complete, the time allowed the Contractors being 3 years. The work was carried out under the direction of Sir Maurice Fitzmaurice, C.M.G., Chief Engineer of the London County Council, and the author was the resident engineer.

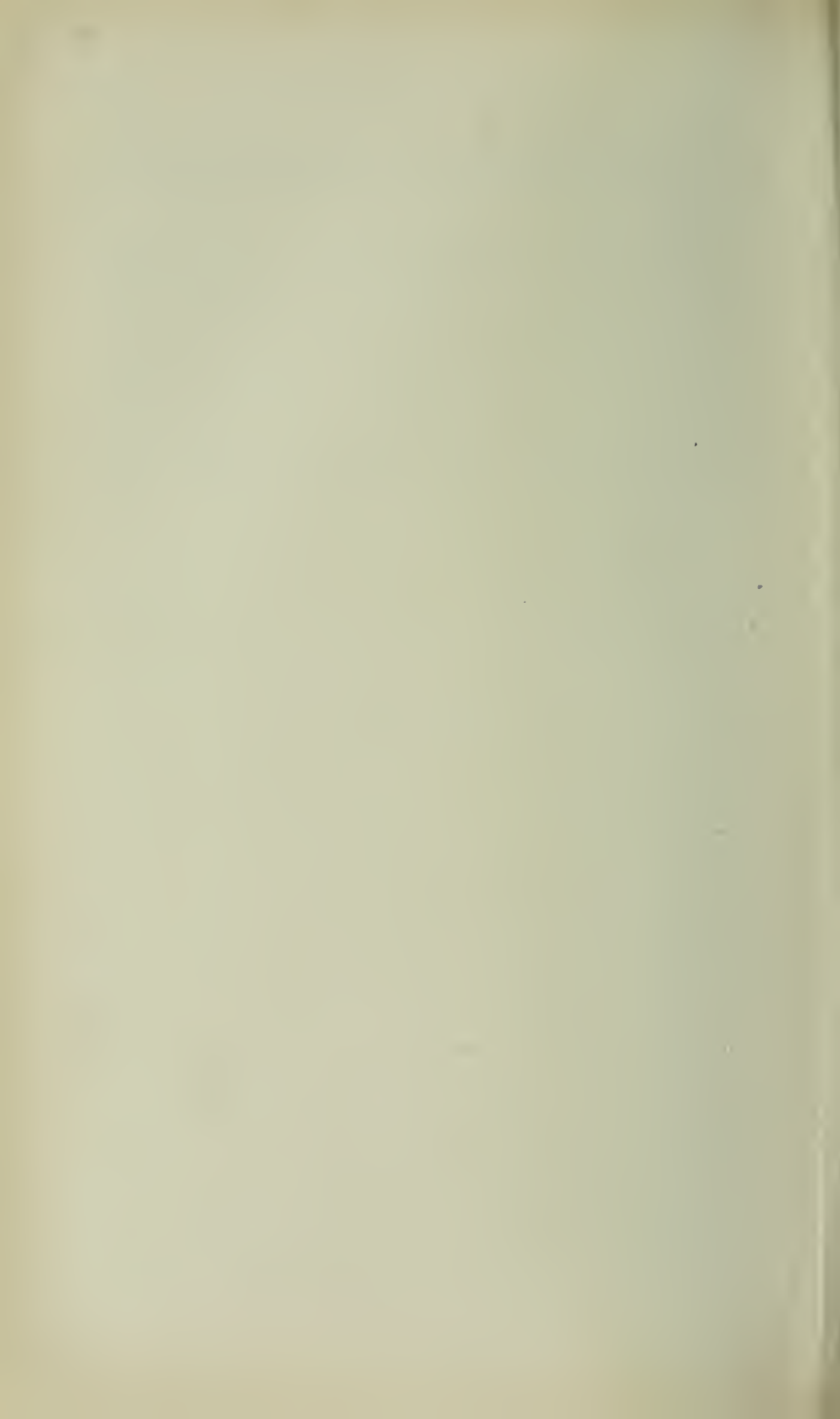


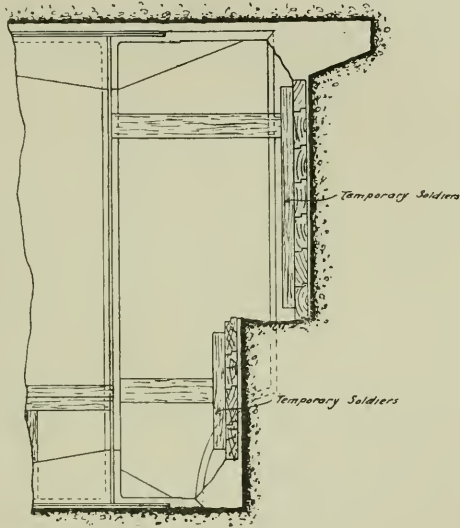
PLATE I.

JOURNAL OF THE SOCIETY OF ENGINEERS (INCORPORATED),

September, 1912.

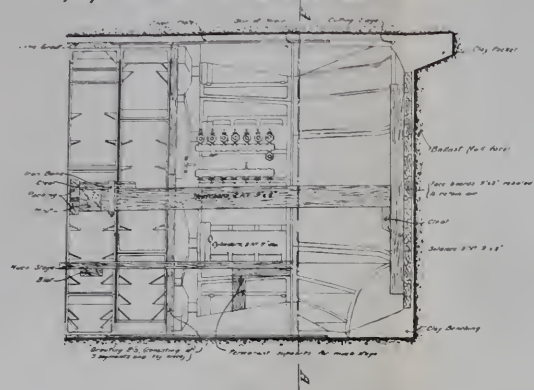
Preparing new pocket prepared and
position for next advance

from

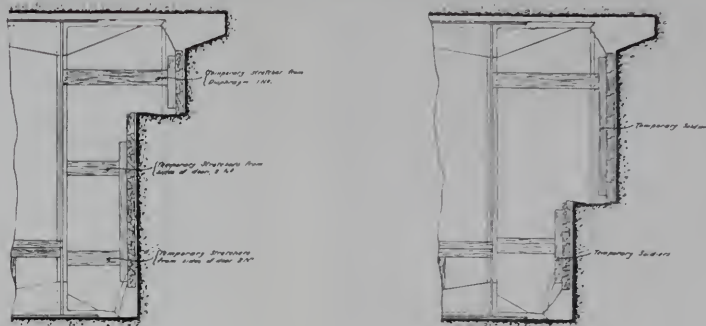


Scale 1/4" = 1 foot

Longitudinal Section showing face prepared for shield to advance



Longitudinal Sections showing non-pocket prepared and face in course of excavation for next advance

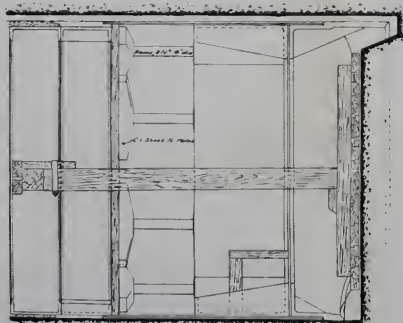


METHOD OF CONSTRUCTING C.I. TUNNEL WITH SHIELD UNDER COMPRESSED AIR.

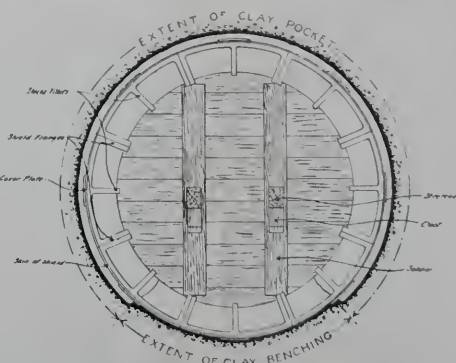
Scale $\frac{1}{4}"=1$ foot.

Longitudinal Section showing shield advanced

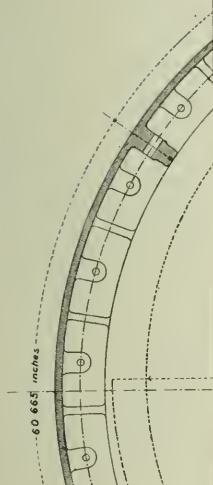
Note: Details of shield and C.I. Tunnel Segments not shown



Vertical Section A-A showing timbering at face etc



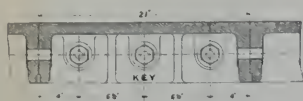
HARRIS O



LONG¹ SECTION THRO'
76" DIA SEWER.



LONGITUDINAL SECTION THRO' KEY



Scale $\frac{1}{2}$ " = 1 foot.

October 7th, 1912.

JOHN KENNEDY, President,
in the Chair.

TOWN PLANNING FROM AN ENGINEERING ASPECT.

By ERNEST R. MATTHEWS, A.M.Inst.C.E., F.G.S.
[Member].

The architectural aspect of town planning has been much discussed of late, but from an engineering standpoint the subject has had less attention. It is easier to regard the matter from the former point of view, for a mere reference to town planning raises in one's mind such questions as whether the houses are to be 12 or 40 to the acre; are to be set back 10 or 30ft.; are to be detached, semi-detached, or in terraces; whether some portion of the area to be laid out shall be reserved for large residences, other portions for workmen's dwellings and bungalows, others for shops, and a further area for factories; or whether the two latter are to be kept out of the area entirely.

At Ruislip-Northwood the town planning area is divided up as follows:—

Part of site area to be occupied only by bungalows.
“ “ “ “ “ “ shops.
“ “ “ “ “ “ ordinary dwelling-houses and larger residences.

The provision of open spaces for parks and recreation grounds, and of sites for public buildings, monuments, etc., all affect the architectural aspect of the subject; but from an engineering point of view, many other important matters have to be considered. As town planning in a residential district is very different from that in a manufacturing centre, we will consider the two cases separately.

(A): TOWN PLANNING IN A RESIDENTIAL DISTRICT.

The town planning scheme prepared by the author for the Bridlington Corporation, part of which is shown on Plate II., is one affecting a purely residential area. In preparing such a scheme the first matter to be dealt with is to fix the area to be planned. A knowledge of local conditions and requirements is absolutely necessary in deciding this; and those parts of the town in which building operations are likely to proceed most rapidly should be included in the area.

This area having been decided upon, and the Local Government Board's sanction to prepare a scheme for such area having

been obtained, the next point to receive consideration should be the direction, width, and method of construction of the various roads. Let us now consider these three points together.

(1.) *Main Arterial Roads*.—At the outset the direction of the through-traffic roads should be fixed, and these should be in such a position that direct means of communication will be provided between one busy part of the town and another, or they should connect up important existing roads. The position of most roads will be determined by the best direction for main and intercepting sewers, and this is a matter for the decision of the engineer. Plate II., which is the author's suggested scheme for the planning of a certain portion of Bridlington, which now consists of fields, shews certain arterial roads illustrating this point. The author strongly urges that none of such roads should be less than 75ft. in width, and that they should be constructed of tar macadam in order to ensure a minimum of dust and noise. The footpaths should be of asphalte, the road should be provided with grass margins and trees, and the author recommends that they be of the section shewn in Fig. 1, the houses being set back 25ft., making a total distance between the buildings of 125ft.

A brief description of such a road is as follows :—

Width of carriageway	..	..	35ft.
Width of footways	..	..	10ft.
Width of grass margins	..	..	10ft.

Such a road is of sufficient width to take a single line of trams in crowded parts and a double line on the outskirts.

The author suggests the following method of construction :—

Foundation.—The sub-foundation having been carefully prepared and shaped to the finished profile, the foundation should then be laid ; this may consist of hand-packed rubble stone, preferable sandstone, or (as at Bridlington) of brick bats well rolled in with a 10-ton steam roller. In the case of a rubble stone foundation a thickness of 9ins. will probably be sufficient ; these stones will be laid on edge and will vary in length from 6 to 9ins. and in thickness from 4 to 6ins. and be laid lengthways across the street. After the rubble stone has been carefully laid, it should be “ blinded ” with broken bricks, broken concrete, or broken stone so as to fill up the spaces between the stones. A 10-ton steam roller should then be applied, the road being well watered, until an even surface is obtained. Where a brick-bat foundation is used, the author's practice has been to make the depth 12ins. after rolling.

Tar Macadam.—The stone for this may be limestone or one of the softer kinds of granite. The author has found Scotch

THROUGH TRAFFIC STREET.

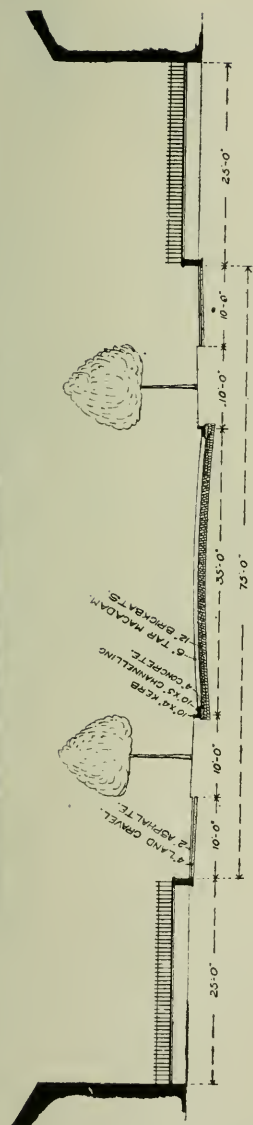


FIG. 1.

SECONDARY STREET.

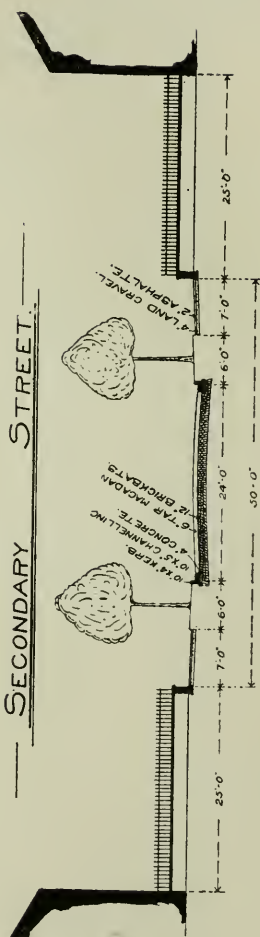


FIG. 2.

granite to be admirable for this purpose, and has used it very considerably for tar macadam, greatly preferring it to limestone, after several years experience with the latter. The stone should be in three sizes, and as regards the relative quantity of each size the author concurs with the suggestion made by Mr. John S. Brodie, M.Inst.C.E., the Borough Engineer of Blackpool, as follows :—

60	per cent.	$2\frac{1}{2}$ inches.
30	„ „	from $2\frac{1}{2}$ inches to $1\frac{1}{2}$ inches.
10	„ „	„ $\frac{3}{4}$ „ „ $\frac{1}{2}$ „
		All below $\frac{1}{2}$ in. being discarded.*

The tar macadam should be laid and rolled in separate layers, being rolled first with a 6-ton, and afterwards with a 10-ton steam roller. The author suggests a total thickness of 6ins. of metal after rolling.

The metal should be thoroughly dried, and all dust removed before mixing with the tar, which should have a temperature of about 260° . The author has usually had the mixing done by hand, but there are many excellent mechanical mixers in the market, and he would recommend the use of these. The estimated cost of constructing such a road at Bridlington, with brick-bat foundation, would be £4 13s. 8d. per lineal yard of roadway, including footpaths, grass margins, and tree planting.

(1a) *Secondary Roads*.—The secondary roads which are important roads, not carrying through-traffic, might be 50ft. in width, constructed in the same manner as the arterial roads, namely of tar macadam, but of the section shewn in Fig. 2. The set back of the houses in these roads might also be 25ft. and the distance between buildings would be 90ft.

Width of carriageway		24ft.
Width of footways		7ft.
Width of grass margins		6ft.

A road of this width will allow three lines of vehicles passing. The estimated cost of such a road at Bridlington, would be £3 9s. 9d. per lineal yard.

(1b) *Subsidiary Roads*.—These are roads which carry practically no traffic except vehicles coming to the houses in such roads. Under these circumstances they need only be very narrow, say 28 or 30ft. with the houses set back 20ft., and might be constructed in the manner shewn in Fig. 3. These also, in the author's opinion, should be of tar macadam, with a thickness of $4\frac{1}{2}$ ins. of metal, and the foundations might be a

* "Suggestions towards a Standard Specification for Bituminous-bound Carriageways," by John S. Brodie, M.Inst.C.E. Paper read at the Institution of Municipal and County Engineers' Annual Meeting, 1912.

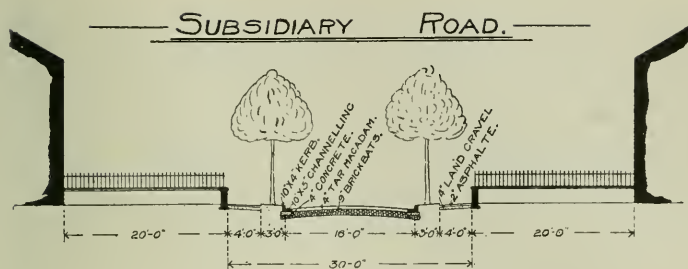


FIG. 3.

trifle lighter than those in the more important roads. While a large amount of heavy traffic will not come upon them as upon the roads already referred to, a certain amount of such traffic will do so in the way of loaded furniture vans, and other occasional heavy vehicles, and the road should be capable of carrying such loads.

Width of road	16ft.
Width of footways	4ft.
Width of grass margins	3ft.
Depth of road foundation	9ins.
Thickness of tar macadam	4½ins.

It may be argued that a width of 16ft. is insufficient, and it must be admitted that it is very debateable whether the cost of maintenance of such a road is much less than that of a road double this width, for the traffic upon a road is nearly always along the centre half of such road, and therefore this concentrated traffic would cause the narrower road to require almost as much repair in proportion to the traffic passing over it as a wider road. The author however urges that as most subsidiary roads are connected to no important roads, that many of them are only culs-de-sac, and that ordinary vehicular traffic on these roads will consist chiefly of light tradesmen's vehicles, a width of 16ft. is sufficient. The estimated cost of such a road would be £2 8s. 5d. per lineal yard.

Cost of Road Construction.—This is a vital point with the landowner, for it determines to a large extent the class of buildings which he must erect if he is to be recouped for his outlay. The by-laws of our towns and cities are unreasonable in their requirements both as regards width and method of construction of roads. How, for example, can one build workmen's cottages when the roads on which these are to abut must be 40ft. in width, with flagged footways, and a heavy type of kerbing,

as is the case in many towns. In the author's opinion it is a waste of money to lay flags and put in say 12in. by 8in. kerbing in such a road, and an equal waste to make such a road 40ft. wide. He has already suggested in this paper that 30ft. is an ample width for a street of this class, and the footways should be of asphalt with grass margins, the latter being protected by stone edging say 10in. by 4in. (see Fig. 3). Not only will this effect a great saving in cost, but roads constructed in this manner will present a more rural and pleasing appearance.

The by-laws requiring roads to be 40ft. wide, oblige the man who is intent on building small houses to erect these with narrow frontages and deep backs, a class of house which is objectionable in many respects; a wider frontage with a shallow back being far preferable. The author deprecates the terrace type of cottages, which have been designated "colliers' rows"; this class of house would in many cases not have been erected if it had not been for the cost of roadmaking, required by the by-laws, making it necessary for the landowner to crowd as many houses as possible on to his land.

It sometimes happens that a residential area in time becomes one through which heavy traffic passes to an industrial area which has sprung up beyond. Who is to pay for the reconstruction of the through-traffic roads in the residential area should such conditions arise? A proposal has been made, with the principle of which the author entirely agrees that "in laying out land for residential purposes the developers should be called upon only to lay out and construct such roads as are needful to deal with the traffic of such area; and in the event of existing industrial conditions or future developments causing a need for heavier traffic-bearing roads through these residential areas, the extra cost of such roads, over the cost of roads constructed for domestic traffic, should be borne by the community."*

The Widening of Existing Roads.—In designing a town planning scheme it will probably be necessary to allow for the widening of some of the existing roads. This has been the case at Bridlington, where Cardigan Road, which now averages 36ft. in width, is to be widened to 70ft. In this instance the East side of the road is built up with large residences, but on the West side no buildings have been erected up to the present. The owner of this vacant land, however, is now desirous of erecting houses on that side of the road, and the Corporation are asking him to give up a 35ft. strip of land for the purpose of increasing

* Paper read by Alderman W. Rhodes of the Chesterfield Town Council at the National Housing and Town Planning Conference, at Manchester, 1912.

the width of the road. Experience has shewn that owners of land in various parts of the country have, generally speaking, been quite willing to give up a portion of their land for road widening purposes, for the reason that if their remaining land abuts upon a wider road it will be of more value to them, and the same argument applies to any houses which the landowner may erect facing the wider road. The Corporation would of course construct the road. This matter of the improvement of existing roads is an important one, and must have full consideration when preparing a town planning scheme.

The diversion of existing Public Footpaths.—In preparing a scheme it is often advisable to improve the direction of existing public footpaths; for which purpose, full powers are given by the Act, and the engineer should give careful consideration to this point.

Open Spaces.—In planning a residential area, it is necessary to determine the best positions for parks, tennis courts, bowling green, children's playground, garden enclosures, sites for future public buildings such as public library, town hall, municipal offices, etc., unless the town is already well provided in that way, and land should be reserved for these purposes. In these matters the engineer will confer with the architect, and of course consult the various landowners and others who have interests in the scheme, and it should here be noted that great tact on his part will be required in order to ensure the best results for the Corporation he is serving.

(2) *Sewerage and Sewage Disposal.*—Having dealt with the roads in the proposed area, the next matter for consideration is that of sewerage. The engineer must ascertain (a) if the existing sewers and disposal works are capable of taking the drainage from the proposed area, and if not whether it is proposed to enlarge them, or to construct new sewage disposal works for the area to be laid out, (b) whether the levels permit of the area being drained into existing sewers, (c) how the storm water is to be dealt with.

At Bridlington, if a large area is added to the town as proposed, it will be necessary to take out the existing 12in. Northern Outfall Sewer which discharges into the sea below L.W.O.S.T. on the North Foreshore, and to put in a 24in. or probably 30in. outfall in its place, also to enlarge the existing screen chamber, and to put in larger sewers for about a third of a mile, from the outfall sewer to the S.E. corner of the area.

Then again on the South side of the town, a portion of the area near Bessingby included in the scheme is too low to be drained into the Corporation sewers, and while some of the front land may drain into the existing sewers if the latter are lowered

5ft. (and no doubt this will be done), the remainder of the sewage will have to be dealt with by the construction of disposal works within the area itself, or be discharged by means of a new outfall into the sea.

These instances of the difficulties that one meets with in designing a town planning scheme may be of interest to the members. The land developer should be expected to pay only for sewers of sufficient size to drain the area, and if he is required by the Local Authority to put in larger sewers, such as may be required eventually if the area is very considerably extended, the authority should pay the difference in cost.

As to the disposal of storm water, the author does not expect to meet with much difficulty in that way, as several good outlets are available. Separate surface-water drains will be laid in most of the roads, and these will be connected up to the existing surface-water drains.

(3) *Lighting*.—The lighting of the area by means of gas or electric light is a matter of great importance, and the cost of the laying down of mains and cables from the nearest supply will have to be ascertained; if the Corporation own these undertakings, they may have to seek powers to extend their lighting area in order to include the town planned area.

(4) *Water Supply*.—The same remarks apply to the supply of water in the area.

(B). TOWN PLANNING IN A MANUFACTURING TOWN.

The planning of an industrial town or city is a far more complicated matter than that of a residential town. From an engineering and economic standpoint a number of important matters have to be considered; some of these are as follows:—

(1). The first point to be decided is the position of the industrial area; to arrive at this one must have local knowledge: that is to say, information regarding existing trades and manufactures, and which of them is likely to develop considerably; the scheme should also be arranged for the inclusion if necessary of any new industries, for it must be borne in mind that the industries of to-day in some of our towns were not thought of a few years ago, and that every month fresh industries are being started, some of them doubtless having come to stay. The motor industry might be cited as an example.

(2). The proximity of this area, with its works and factories, to railway sidings and to main lines for the supply of the raw material, coal, etc., and for the disposal of the finished materials, is a very important matter. Land adjoining railways, rivers, and canals will, generally speaking, be admirable for inclusion in

a manufacturing area. In certain trades of course it is important that the works shall be situated where there is much water. Bleach and dye works for example are generally found on the banks of a river, stream, or canal. These points will have to be considered fully by the engineer when planning the industrial area.

Before deciding on any particular positions for railway sidings, the engineer will naturally consult the railway officials; it is preferable that there should be a general siding leading to a number of smaller sidings. It has been suggested that it will pay a landowner in some instances "to give the land to the railway for the siding or sidings in order that engines might bring the goods nearer to the factories and yet remain upon the railway companies' land."*

(3). The facilities for vehicular traffic to and from this area. The position of main arterial roads, relative to the proposed area.

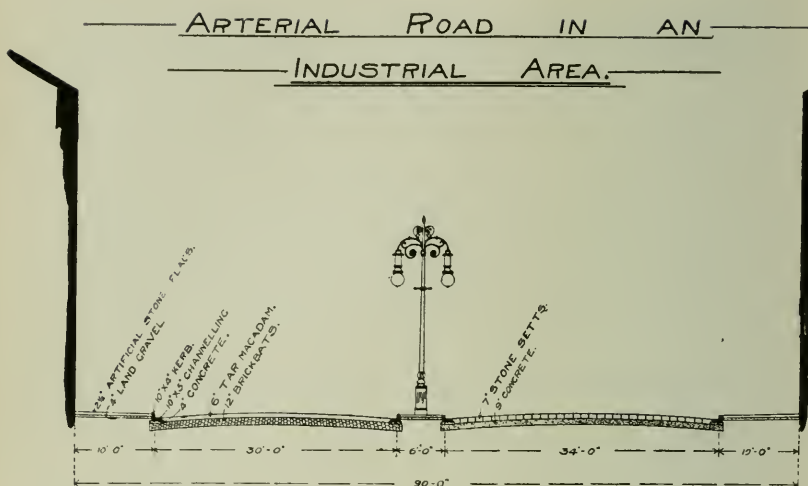
While in a residential area it adds to the picturesqueness of the district if the roads are radial in plan, (and the author would strongly recommend this), in an industrial centre, direct communication between the area and the railway, wharf, and principal parts of the city is of the utmost importance. The connection of the proposed arterial roads with existing roads is also an important matter.

(4). The necessity for constructing any new roads leading to this area in such a substantial manner that they will carry the heavy traffic likely to come upon them. All streets of this class should be paved with stone setts laid on a good concrete foundation, and they should be wide enough to take a double tramway track.

(4a). The provision of roads for rapid and slow traffic.

Fig. 4 (p. 10) shows a cross section through an arterial road leading to an industrial area, and illustrates what the author recommends as to the provision of two distinct streets running parallel with each other, but intended one for rapid the other for slow and heavy traffic. He suggests that such a provision is necessary owing to the increasing number of motor cars and other speedy vehicles using the roads. It will be seen that the footpaths are flagged, they are 10ft. in width, and that the rapid-traffic road is constructed of tar macadam, and is 30ft. wide, while the slow-traffic road is paved with setts and is 34ft. wide, a 6ft. refuge or footway dividing these two roads. The total width of the street would be 90ft. It is not suggested

* "Industrial Development," by Councillor W. G. Wilkins, J.P. Proceedings of the National Advisory Town Planning Committee.



that trees should be planted in such a street. Some have recommended that the width of the main arterial streets should not be less than 100ft. or even 120ft. but the author sees no reason why they should be of this great width.

(5). The area to be occupied by workmen's dwellings, and the proximity of this to the industrial area.

There is a difference of opinion regarding the best position for the houses of the workpeople. Some maintain that these houses should be away from the industrial area, but situated in an adjoining housing area, while others consider the houses should be built in the same locality as the works and factories, so that the factory hands will be close to their work, and will not have to walk some distance to their homes. The author favours the first suggestion chiefly on the grounds of health. Easy communication can be provided between the two areas, and if they adjoin there need be no reason why the workmen cannot get home to dinner each day. Larger gardens can be better arranged for if the houses are in a separate area, and the fact of the dwellings being away from the works has a tendency to enable the factory hands to forget their daily avocation after working hours.

The author certainly favours keeping the works and the people apart. If the factories are on one side of a river and the houses of the people on the other, ample provision should

be made by means of bridges for easy communication between the two sides.

(6). The supply of electrical energy to the manufacturing area for power and lighting purposes :—

This is an absolute necessity in an industrial area. The use of electricity for power purposes is becoming more and more common, and from a smoke nuisance point of view this is necessary, for in many cases the proposed industrial area will be adjacent to a residential area.

If the electricity supply of a town or city is in the hands of the Corporation, the Electrical Engineer should be asked to advise his Committee to obtain, if necessary, powers to extend their area of supply, so as to include this proposed industrial area. Cheap rates for power and lighting purposes should be offered to the factory proprietors to induce them to take the current.

(7). Whether water carriage is available, and if so, the position for wharfage upon rivers or canals must be selected, and the estimated cost ascertained.

(8). Provision of water and gas. It is necessary to consider the advisability of supplying water power in an industrial area.

(9). Efficient sewerage and sewage disposal system.

(10.) The disposal of storm water.

(11). That the area is sufficiently large to allow of ample provision being made for the future development of the various industries.

(12). In deciding the position of the proposed industrial area, the prevailing winds should be taken into account, and the area selected should be one so situated that the prevailing winds will carry the smoke away from the residential area.

(13). The advisability of constructing subways under the main arterial roads to accommodate gas and water pipes, telephone, telegraph and electric cables, hydraulic mains, compressed air and sewer pipes.

This in the author's opinion is a matter which in this country has not received sufficient consideration. The present method of laying sewers, water mains, gas mains, etc., under our streets is altogether unsatisfactory. These streets are continually being opened for the purpose of connecting to one or the other of these, and this constant opening of the principal roads is an intolerable nuisance, while the reinstatement is not always satisfactory, and leads to a great deal of correspondence with the departments concerned relative to the unsatisfactory reinstatement of trenches.

The construction of a subway is the remedy, and the author recommends this, but owing to the cost he would build the subway in the main arterial streets only. Fig. 5 is a suggestion he makes as to the type of subway that might be built. Reinforced-concrete he considers to be an ideal material to use in a structure of this kind.

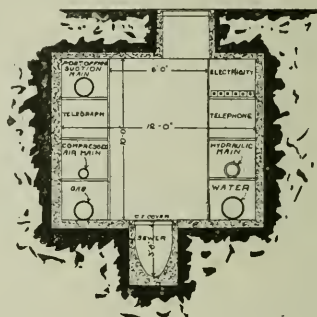


FIG 5.

SECTION OF SUBWAY.

(14). *General*.—In the industrial area might be included refuse destructor works, tramway depôt, car sheds, abattoirs, ice factory, and cold stores; it is always best to group these together, and to place them as far away from the residential area as possible.

(15). The construction of tramways or light railways in the area is also a matter of consideration.

(16). Folly of limiting the height of buildings. If the maximum height of the buildings which will abut on the new street is specified in a town planning scheme, the owner of the land will be almost sure to build to that height considering it more economical to do so. If it be four-storey buildings that are allowed and not higher, then there is a danger of a monotonous row of four-storey buildings being erected, whereas a variation in the height of the buildings will be preferable.

(17). Having decided the industrial area, the residential area must then be chosen, and the developments of this will proceed on the lines already indicated in the first part of this paper.

Brief Description of Bridlington's Town Planning Scheme.—The author will now in conclusion give a few particulars regarding the town planning scheme which the Bridlington Town Council have under consideration.

The area proposed to be included in the scheme adjoins the town on three sides and comprises some 2,805 acres, the total area of the Borough being 2,751 acres. About two-thirds of the area proposed to be laid out is outside of the Borough and in the Rural District Council's area. To avoid any opposition from them in this matter the Town Council have taken the wise course of asking their co-operation in the preparation of this scheme by the appointment of three members of the Rural District Council to attend the Town Planning Committee's Meetings and tender their suggestions; the R.D.C. have agreed to this proposal.

It is not intended to proceed at present with the detailed plan, shewing the whole area laid out as streets, building sites, parks, etc., but to do this in sections, the first of which to be planned is that shewn on Plate II. There is no need for the author to describe the laying out of this area as the plan explains itself; he would, however, state that at present the area consists of fields, the land being worth from £60 to £100 per acre. The width and method of construction of the proposed roads is shewn in Figs. 1, 2, and 3. The sewerage of this area has already been referred to, the Gas Company have power to lay mains within the area, and the Corporation have power to supply water and electricity. If the area is laid out by the landowners in the manner shewn on the plan, the land will be converted into building land worth from 7s. to 10s. per sup. yard. The Corporation are hoping to obtain land free for the laying out of the parks, recreation grounds, etc., shewn on the plan. The area of this first section is 175 acres, and 25 workmen's dwellings are about to be erected on part of it (See Plate I.).

The author has endeavoured in this paper to point out the extent to which town planning affects the engineer. Landowners are welcoming the adoption of town planning throughout the country, as they find that if their land is left outside the area proposed to be laid out it may be undeveloped for years. Local authorities on the other hand have now the opportunity of extending their towns on modern lines and so making the England of to-morrow a country of beautiful cities with open spaces and wide streets. Many authorities have already taken advantage of these opportunities and have prepared town planning schemes, many others are now doing so, and it is the opinion of the author that in the near future there will be scarcely a town in this country of any importance that has not its town planning scheme in hand. In order to ensure the best results it is necessary in this matter that the engineer shall co-operate with the architect and that the one shall appreciate the work of the other. Great tact will also be required in dealing with landowners and other interested parties, and experience has

already shewn that the landowner is not, except in obscure cases, an unreasonable man to deal with, and that if it can be made clear to him that the development of his land on town planning lines will be a great advantage to him, he will be found willing to co-operate with the local authority, and if necessary give up to the authority pieces of his land for street widening, provision of open spaces, etc. Many landowners have done this and have become most keen on town planning.

DISCUSSION.

The **President** moved a vote of thanks to the author of the paper.

The following written communications were then read :—

Mr. John S. Brodie wrote : To a certain extent the architectural aspect of town planning must of necessity take precedence of the engineering standpoint, and, within certain limits, the engineer will step in when the architect has completed the rough outline of his plan, just as, in the architect's design for a great building, the engineer can be usefully invited to confer on details with which of necessity he must be more familiar than the architect. The contour of the ground must to a large extent govern its laying out, and such questions as main drainage must, of course, be left to the engineer.

The author suggests three classes of roads. I have for many years used six standard forms of roadways in Blackpool, so that each type of roadway may be adapted to the economical conditions for the development of the land, which are, after all, paramount in any well-devised scheme of town planning. Referring to the cross-sections in Figs. 1, 2, and 3, I am much more inclined to have wide spaces between building lines than grass margins as part of the roadway, except in special cases where they can be well looked after, as such margins tend to become untidy and depressing. I cordially endorse the author's remarks as to the cost of road construction.

The benefits of ultimate wide arterial roads can be quite easily secured for future use by authorities acquiring land for highways of an ultimate width of 60 to 100ft., and allowing the abutting owners in the meantime to enclose within their front gardens or lawns so much of the ultimate width required as is not necessary for immediate road purposes ; and it will be found that in many cases a 36ft. roadway—of 21ft. carriageway and two 7ft. 6in. footpaths—will be found ample for present purposes, and the land for future widening being secured, the expenditure on such future widening can be deferred until the volume of traffic warrants it, and should then be borne by the community and not by the abutting owners.

Perhaps the German method of purchasing the freehold of land immediately adjacent to the town area—a method adopted at Blackpool with much success for some years past—is preferable to any other, as the municipality rather than the individual landowner reaps the advantage of the increased land values.

Mr. Sydney H. Morgan wrote : The engineering aspect of town planning is of primary importance, and the municipal engineer is particularly fitted by his training and local knowledge to deal successfully with it.

The author advocates tar macadam for use on main arterial roads in a residential district. I am not sufficiently acquainted with the conditions at Bridlington to express an opinion as to the advisability or otherwise of this method in that particular instance, but as a general policy I cannot agree with the author on this point. At Prestwich there are some very fine roads of tar macadam in the residential quarter. Tar macadam is not suitable to main or even secondary road traffic. With heavy traffic—and a main arterial road must sometimes bear heavy traffic—the surface is liable to wear unevenly and is most difficult to repair neatly. Granite rock asphalt laid on a bed of concrete would fulfil Mr. Matthews' conditions as to dust and noise, while at the same time standing greater wear and tear.

Again, I dissent from his recommendation to use tar macadam on an arterial road in an industrial area.

A double tramway track will certainly be necessary on an arterial road, but the author does not appear to provide for it. Would he place it on either of the roadways shown on Fig. 4 or on a separate portion of the road ?

In the case of subsidiary roads I would go further than the author both as regards width and mode of construction. Where the road is so designed that it will not be used by through traffic, but only as an approach to a few houses, 20ft. or 24ft. in width might be sufficient, provided the houses on both sides were well set back.

Trees, instead of being planted along the footways (as shown on Fig. 3), where in so narrow a street they become an obstruction, may suitably be planted just inside the gardens. In this manner both the minimum width of road and the pleasing avenue of trees are secured. Tar macadam in such a street seems unnecessary expense, and granite or whinstone macadam on a good foundation would meet all the needs of the case.

Mr. F. W. Platt wrote : The author expresses the opinion that houses should not be erected near to industrial areas, but should be situated in an adjoining housing area. This doubtless would be an ideal condition, but owing to the sporadic and unregulated growth of modern towns in the North of England it would be most difficult to put into practice there.

Engineering science might well be directed towards devising a town planning scheme wherein houses and factories or workshops, although in contiguity, yet have healthy and pleasant surroundings. It is not every business of an industrial character that is objectionable, and if the motive power for the machinery could be generated in some central area, there seems to be no reason why industrial and domestic buildings should not be within the same district.

The types of road given in the paper suggest the thought: Is it necessary in the residential areas for the through traffic roads to be made 75ft. in width in the first instance, that is, assuming the residential area will be nothing but a residential area? and is it absolutely essential or even desirable for the main and intercepting sewers to pass along the main arterial roads unless they are enclosed within a subway as suggested by Mr. Matthews?

Main arterial roads are usually fully occupied with traffic through most hours of the day, and such a road would not be conducive to the quietness and freedom from dust that is needed for a residential area, and, further, if any alterations or additions were needed to the sewers or other means of public services beneath the surface of the street, unless they were all enclosed in a subway, the spaces needed to make such alterations, &c., could be less spared in a main arterial road than in any other road. Of course, if a subway were provided this difficulty would not exist, but where such suggestions have been made to local authorities the enormous expense of making a subway has been a bar to its construction.

Mr. Matthews' remarks as to the folly of limiting the height of buildings in an industrial area should be closely considered. His experience has doubtless been that of most municipal engineers, that to prescribe a maximum height often means to create a stereotyped height, and if the picturesque is to be carried into the industrial area—and there is no reason why it should not be—a regulation limiting the height of buildings would be the most certain means of creating ugliness.

Mr. A. H. Campbell wrote: The orderly development of centres of population has for long engaged the attention of municipal administrators, and at last the all too tardy powers conferred by the Town Planning Act open out a new scope for the engineer and demand the exercise not only of engineering skill, but of those not less indispensable talents of common sense, persuasive force, and patient plodding that are most certainly required to carry through a town planning scheme against a great variety of conflicting interests.

I do not find that Mr. Matthews has dwelt very much upon that all-important part of the preliminary survey work known as "the Altitude Survey," commonly called "the Contour" of the

area. If the land be of a hilly or undulating character, a correct contour taken at 5ft. to 10ft. vertical intervals is an absolute necessity.

One other feature of a good town plan is the importance of good vistas. In the disposition of the roads, the grouping of the buildings, the introduction of landscapes, there should be developed that artistic sense that delights in terminal features to the leading avenues. Engineers should endeavour to utilise the means open to them of embodying this attractive feature in the plans they prepare.

The proposition advanced in the paper that the routes of roads are determined chiefly by considerations of drainage is one that I cannot accept ; other equally important elements, such as the positions of railway stations, the transit question, &c., should influence the disposition and direction of roads.

The locality of the industrial area is another part of the plan that introduces controversy. Nowadays when electricity is so cheap and power so readily obtainable from a common generating centre, I see no reason why factories of good design, becoming elevation, and with electrically-driven machinery, may not be erected in the midst of habitations.

Mr. H. Gilbert Whyatt wrote : A portion of the county borough of Grimsby which the Corporation has in mind as suitable for a town planning scheme is on the verge of a district entirely residential in character, but at the same time it is certain that provision will have to be made for factories. The question has been discussed as to whether it is desirable for the local authority of a practically entirely residential district, as one imagines Bridlington to be, to include the whole area of the borough in its application so as to limit the erection of works and factories to one particular area in the town or to exclude them altogether, but it would appear that even if such a scheme received the approval of the Local Government Board, the law could not compel the owner to use a building as a residence and to plant the garden with flowers and shrubs ; it is quite open to him to use the house as a workshop and the garden as an ugly storeyard in connection therewith, provided the house can be made convenient for the purpose without the erection of additional buildings. Even the erection of additional buildings could not be prevented if constructed as stables, coach-houses, granaries, garages, &c., and used without alteration for the purposes of the factory.

With regard to the question of a local authority paying for the extra width of road over that required by the by-laws, this can only be done to any great extent by a local authority which has a very high rateable value. The usual period for a loan allowed by the Local Government Board for road construction is eighteen or twenty years, and the annual payment is, respectively,

£7 14s. 9½d. or £7 3s. 11d. per cent., which will have to be borne by the rates ; whilst on the other hand, with a reduced number of houses per acre, the local authority will have a less income from the estate. The real offset is a reduction in the death rate. In the case of the landowner he receives a less ground rent owing to the restrictions placed upon the area and the limitation of the number of buildings per acre, but at the same time his expenditure on the construction of streets is less, and, taking the two, he suffers no financial loss.

The present writer ventures to disagree with the author as to the construction of a subway on the lines indicated in Fig. 5, except in so far as it tends to reduce the number of longitudinal trenches in a road. The latter are not very numerous, only occurring when it is necessary to lay a new main, and only recurring when enlargements or extensions become necessary. The cross trenches are the most numerous and the most exasperating, for no sooner has a road been thoroughly repaired than it is cut up a dozen or more times within six weeks to make connections of various sorts. To have a subway as sketched by the author would be to increase the difficulties. Now the electricity cables, and often the gas mains, are laid under the footpaths, and the cross trenches are very short ; they would all be the same length under the scheme, and would always cut up the roadway. Again, all drain connections would be very difficult to carry out and to supervise, with the sub-structure in the way, and the limited headroom below the concrete carrying the gas and water pipes. Assuming one side of the subway to be east and the other west, there are difficulties in connecting the water and hydraulic mains and the telephone and electric cables on the east side with the buildings on the west ; and conversely connecting the gas main, compressed air main, &c., on the west side with the buildings on the east side of the street, but to an engineer these are not insuperable.

Mr. J. F. Jodrell Reynolds wrote : The recently published premiated and other designs for the Australian Federal capital show clearly how essential it is that the architect and engineer should work together in the preparation of such schemes.

If any of the five roads (Plate II.) converging upon the circus should become through-traffic routes, it is probable that the ornamental garden shown in the centre will have to go. While rounded corners for forecourt fencing at road junctions is excellent from a traffic point of view, as allowing a better line of sight, it would be better—for safety purposes—that the kerb line should be extended and only slightly rounded at the corner, with a lamp to protect it, thus offering less inducement to motor vehicles to take these corners at dangerous speeds.

The suggested carriageway width of 35ft. for main arterial roads, if any considerable volume of traffic has to be provided for, or may be anticipated in the future, appears to be insufficient. It allows only for one line each of fast and slow traffic with a single overtaking space. There is certainly no room for either a double or single line of tramway. Judging by past experience, the only safe rule is to allot a width of roadway sufficient for all anticipated vehicular traffic, apart from tramcars, and then to add at least 15ft. of width where a tramway is to be provided. In cases where a town is not already committed to tramways, the provision of a trolley vehicle system is well worth consideration.

For subsidiary roads, which will never become through traffic routes, the author's proposals are excellent, and capital costs may safely be reduced. The trouble is that we cannot always foresee all future traffic requirements, therefore it might be well for certain subsidiary roads to have grass margins of increased width, to allow of the roadway being readily widened when required. Grass margins are a pleasing feature if kept in good condition and not left solely to the care of the ordinary roadmen. It might be necessary to lay a width of gravel opposite front garden entrances, otherwise tradesmen and other callers from the carriageway, may wear unsightly patches on the margins.

The method of construction shewn in Fig. 4, is interesting and may be the best compromise in some situations, but there are several objections that might be capable of a better solution : (1) The difficulty of defining the class of vehicle to use each road ; (2) Vehicles crossing from the slow to the fast side to deliver goods ; and (3) One side would be unduly favourable to shops and might make a considerable difference in site values. Possibly a triple road, two "slow" roads 16ft. wide and a centre "fast" road 30ft. wide might meet this case.

The question of the relation of the area occupied by the workman's dwelling to that occupied by his factory or works, must depend largely upon the size of the town. Undoubtedly it is better for him to be some distance away, but it is often impossible to provide for his transport owing to the shortness of the mid-day break and the fact that it occurs at the same hour for all works.

Any suggestion that will keep the natural enemies of a good roadway—the gas, water, etc., companies—from cutting them up, would be welcome. This is certainly the case with the author's proposed subway. Even if they have to be constructed in duplicate, on either side of the road, below the grass margins or footways, they should pay for themselves in the course of time, especially where it is possible to obtain a rent from the users. In cases where the capital cost would be too high,

the mains might be laid below the margins, with subways at all side road crossings.

Mr. Arthur Bowes wrote with respect to the construction of subsidiary roads: It might be possible to reduce their cost still further, if more use were made of the methods advocated by Mr. Raymond Unwin, of disposing the buildings in quadrangles and culs-de-sac, so that through traffic becomes impossible. As to trees on roads, they might perhaps be better placed next to the garden walls, giving an appearance of greater width to the road, rather than next to the roadway, where when fully grown, they are apt to shade the roadway too much.

The authors proposal to provide twin-roads for fast and slow traffic is an excellent one. There seems to be no doubt that this course will have to be adopted all over the country in a few years, and it is wise to make the provision in a town-planning scheme. The subway, also, will be a means of saving much expense and annoyance in the future. It is essential that the heights of buildings should be controlled, both from an architectural and an economic point of view, for if no limit were fixed we should get hideous blocks of buildings.

Mr. J. W. Cockrill, wrote :—So much of Mr. Matthews' paper is the outcome of real practical experience in his own district that it cannot be controverted, but he insists on too high a standard for the road making. The estimates given are low for the work proposed and could not be executed for the money in all parts of the country. It will also be urged that the plan (Plate II.) is wasteful in space occupied by the roads and that the sections of the roads given are unnecessarily costly, but from the point of view of the official who will have to maintain them and to meet his Council for years after they have been adopted, it is necessary that the footways should be paved and the grass margins kerbed.

Mr. Burns' Town Planning Act gives the opportunity of negotiating with the land owners, and the following quotation from a paper read by Councillor W. G. Wilkins, J.P., at a meeting convened by the Housing and Town Planning Council in London, in April last, gives in my opinion a strong reason for Local Authorities proceeding with a scheme :—

“ The Housing and Town Planning Act gives remarkable
 “ facilities for the making of bargains between local au-
 “ thorities and land owners, and the extent to which the
 “ Act is used will largely depend upon the extent to which
 “ those interested in the land meet those interested in
 “ civic progress in friendly co-operation for mutual benefit.”

The by-laws in force in most towns frequently come in for a hostile criticism by a section of the public, especially in their

result on the planning of corner houses and in the question of drainage. As to the first the experience of how sites have been overcrowded where there has been no by-law controlling this matter gives no encouragement to relax this by-law, and in the second case, until the law is altered which provides that each house must have its separate drainage, local authorities will not be prepared to accept the responsibilities involved in giving way on this point.

Other by-laws which are considered as involving curtailment of architectural effect and use of materials might be allowed to drop, but at the present time most local authorities are open to admit anything reasonable in a well designed and substantially constructed building.

DISCUSSION.

Mr. Ebenezer Howard seconded the vote of thanks, and opened the discussion. He said that, not being an engineer, he should have been surprised at receiving the invitation of the Society to open the discussion had it not been for the fact that he knew their Secretary, Mr. Ackermann, and that some years ago he read a paper on the very important subject of town-planning in the open country, before the Society which amalgamated with the Society of Engineers in 1910.

Mr. Matthews' paper was divided into two sections as though those two sections embraced all the possibilities of the case. These were town planning in relation to a residential district, and town planning in a manufacturing town; but he, (Mr. Howard) would suggest that there was a third type of town planning, very seldom thought of at the present time, but which would certainly have to be much considered in the near future, namely, town planning in open agricultural areas. The largest town planning scheme which was now being carried out in England was of that nature.

The town planning enterprise at Letchworth embraced an area more than seven times as large as the old walled-in City of London, for its area (originally 3,800 acres) was now, owing to recent acquirements 4,500 acres. This was a case of what might be called town planning *ab initio*. And surely, town planning in its essential and primary meaning implied the building of a town, and not merely the building of additions to towns, however important those might be, and he did not wish to be understood as suggesting that they were not of very great importance. In Great Britain there were many large growing towns, and, certainly, the method of their development was of very great importance, and attention was very naturally directed to it. Therefore, it was very useful indeed to have such a thoughtful paper as that which Mr. Matthews had presented. If he (Mr. Howard) could add anything to the paper on any of

the branches of the subject with which it dealt, it would perhaps be with reference to the making of such provision with regard to roads as would enable them to be widened at comparatively little expense, if widening was found to be necessary.

At Letchworth they had to deal with two types of roads, first the roads which existed on the estate when it was purchased, and, secondly the roads which had been constructed in the course of development. There was an important county road leading from Hitchin to Baldock, which was in places very narrow, and the architect of the Garden City very wisely advised that the company which was developing the town should do that which Mr. Brodie had suggested in the communication which had been read to the meeting ; namely, they should allow the leaseholders to use certain land which abutted upon that road upon the condition expressed in their leases, that, if such land were required later for the widening of the road it should be given up. This arrangement would probably eventually result in a large saving.

Experience at Letchworth had, he thought, shown that where roads were not wide or important, grass margins were more suitably placed, not between the side-walk and the road, but between the sidewalk and the houses, and it was wise to do what Mr. Brodie had suggested, to let the tenants utilise what would otherwise be a grass margin on the condition expressed in the leases, that they should give up such land if time proved that the road required widening. If that were done, roads could be widened at very little expense. Meantime, of course, such margins must not be dedicated to the public.

The area at Letchworth was developed from the point of view that what was a purely agricultural area when it was purchased, in a few years would become a considerable town with a large number of industries ; therefore the promoters had to consider where they should allow the factories to be placed, and naturally they selected a site near the railway which intersected their estate and which divided it into nearly equal parts. A very large number of quite important industries had grown up on the site. Among these were book-binding and engineering. There were two large motor works, and a third was about to be erected. There were also works for the manufacture of geysers, swiss embroidery, corsets, bioscopes, tapestry, etc., etc.

With regard to the important question of housing the people, and of whether the dwellings should be adjacent to the works or not, it was decided that, as a large portion of the estate was set aside for factory purposes, land adjacent to the factories should be set aside for workmen's cottages. There were only four hundred people on the estate when the promoters purchased it ; now there were nearly eight thousand, and, owing to the proximity of houses to the factories, a considerable number of workmen were

able to go home to breakfast and to their midday meal, and also to play football and cricket within a few minutes' walk of the factory where they worked. This did not in the least degree, as Mr. Matthews rather suggested, tend to lower the health of the people. This was partly because the factories at Letchworth emitted extremely little smoke, the power being largely electrical, and also because the factory area was deliberately placed to the north-east of the town, and because also there were playing grounds and allotment gardens near many of the factories. Indeed, Letchworth was far more healthy than any other town in the kingdom. This was shown by the infantile mortality rate, which was only half that of London, and one-third that of Birmingham, and it was to be noticed that the same causes which tended to lower infantile mortality tended also to raise the vitality, the strength, and the energy of the whole people.

Though it would, of course, be absurd to suggest that the building of new, well-planned towns, combining, as Letchworth did, the advantages of town and country, was the one and only thing to be done, still he hoped that engineers would recognise the vast latent possibilities lying dormant in the millions of unoccupied and unused acres in this country—areas admirably suited for the building of healthy and beautiful and useful towns, which would rival the old towns in a perfectly healthy and natural way, the rivalry tending to produce better results both in the old towns and in the new.

He congratulated Mr. Matthews on the clearness of his paper and also on the number of cottages which he proposed on an acre of land. It was very evident from Plate II. that Mr. Matthews was not contemplating the putting up of forty cottages to an acre or any number of that kind. It was to be hoped that the Bridlington Town Council would back him up in that respect. He (Mr. Howard) ventured to suggest that cottages erected so densely as forty to the acre would very soon be absolutely out of date, for certainly ere long no self-respecting workman would condescend to live in them.

Mr. Holroyd Smith said that he had visited Letchworth Garden City two or three times, and, on the whole, he must compliment the promoters upon the good work which they had undertaken.

At Letchworth Garden City they had avoided, to a certain extent, the plan of laying out all the roads at right angles to each other. In this American system roads from north to south were called "roads," and those at right angles to them were called "avenues," and they were all numbered. But, to get from one corner to another, one had to walk along a distance equal to two sides of the square.

He suggested that the basis of a new town should not be square but hexagonal, so that one could get from south-west to

north-east without going up two sides. It would not be quite direct, but the divergence would be slight. He did not advise a honeycomb plan, but the hexagonal basis would give squares, triangles, polygons, and various other figures. They could then get an architectural effect which did not exist when the basis of the town plan was merely a subdivided square.

He found described and advocated in Mr. Matthews' paper the common absurdity of the cambered road which was to be seen in all parts of England. With a road like that the slightest nervousness or hesitation on the part of the driver sent the car careering on to the footpath. The water drained off the surface of such a road to the sides. In long country roads where they could not make enclosed drains, this might be excusable, but in towns the mud settling at the two sides was objectionable.

A much safer and better form was the "dished" road of hollow cross section with a drain at the centre. Here, if anything went wrong with the steering of a car, it made for the centre of the road and stopped there. Another advantage of the system was that slow traffic could keep to the side and other traffic to the centre. On a barrel-shaped country road a motor car going past a waggon of hay, for instance, had to go into the hedge, and accidents often arose from that cause. At present a drain had to be put in on both sides of the road, but in a dished road a centre drain was sufficient, so that form of road was both safe and economical. With regard to speed of traffic, he thought the road should be divided into three, with the fast traffic in the middle and slow traffic at the two sides.

He had long advocated the gyratory system of dealing with vehicular traffic where two or more main thoroughfares crossed. This system was originated by himself, and was described by Mr. W. Noble Twelvetees in a Presidential Address delivered before the Civil and Mechanical Engineers' Society in October, 1907. It had also been strongly advocated by M. Eugène Hénard.

On this plan the traffic would be constantly on the move, and each vehicle would turn out when it got to its own particular place.

Mr. C. T. A. Hanssen said that his experience of streets draining to the centre was against such an arrangement, because the bulk of the rain water that flowed across a street did not come from the street itself but from the adjacent houses and court-yards. If the gulleys adjoined the kerb, as they generally did in this country, the water reached them quickly. If the whole of the water was allowed to flow to the centre of the street it made the roadway very muddy. The slope from the centre to the side of the road was, however, often much greater than necessary, yet he thought the correct principle was to have the

gully at the kerb, and to allow the centre of the road to drain to the sides.

When town planning in the open country it was very desirable to avoid the concentration of large numbers of people in factories. With modern facilities for electrical distribution of power a system of industrial villages became possible, where people carried out their daily work in their own houses, after the manner of their forefathers. The village should be so laid out that transport from one cottage to another would be just as easy as transport now was from one part of a factory to another. Each workman would have his work in his own home, and have a sufficient amount of garden to provide the greater part of the food required for his household.

A friend of his in Westminster supplied machines for making small cubes of granite, which have been used a great deal in England and abroad for road making. The cubes were laid down on the ordinary macadam foundation and rolled with a steam roller so as to make a solid surface which looked something like mosaic. The Chelsea Embankment had been made in this manner, and he understood the road was almost dust-free, while the tarred roads advocated by the author only substituted a more objectionable black dust for the present white dust. The cube system was not much more expensive than macadam.

He had reported on the Letchworth sewerage when it was first started. There was a slope from one end to the other, and it was possible to arrange the streets in such a way that the sewage could flow by gravitation to the lower part of the site, and it could then be treated at the outfall works without any pumping whatever. It would be a great advantage if all the streets of new towns could be laid out according to the natural fall, so that the sewage disposal works should be in the most natural place.

Mr. E. H. G. Brewster said in regard to subways that the idea of such subways was originally advocated by a Mr. Gordon, who, in 1820, wrote a book on the subject for the purpose of showing how desirable they were for sewer and other pipes. The old Metropolitan Board of Works started the use of subways in London, and now most of the new large London roads had them. One of the earliest was under the Victoria Embankment. Subways were so costly, however, that he did not think that they were likely to become general in new town planning schemes.

As the question of roads was such a prominent feature of all town planning schemes he wished to draw attention to the necessity of well rolling the surface of roadways after they were levelled up as well as after they were made, so as to consolidate them thoroughly. The omission to do this might necessitate the remaking of the roadways. He knew of a road where the

wood block surface had to be relaid owing to the omission of the rolling of the original raw loose surface notwithstanding the fact that the blocks rested upon a layer of 9in. of concrete.

On the question of wide roads he entirely agreed with the author. Roads might be too wide, and, if they were, they were expensive both to make and to maintain.

With regard to the use of small cubes of granite for roadways, which had been mentioned by Mr. Hanssen, they might do in some roads with very light traffic, but as a wheel of an ordinary pair-horse omnibus would crush a granite cube of 1 $\frac{1}{4}$ in. side, as he had seen over and over again, he did not think they were likely to come into common use.

The author had stated that he was not in favour of limiting the height of buildings, but he (the speaker) was in favour of doing so, so long as buildings might be less than the official limit. He was pleased to see that the author had carefully rounded all the corners of the streets shown on his plan. The meeting of streets at sharp angles was a very dangerous thing, and led to many accidents.

Mr. R. W. A. Brewer said that he must support what had been said by Mr. Holroyd Smith, particularly with regard to the shape of the road surface. Engineers had been advocating the concave road for many years, and it was very unfortunate that road engineers had not recognised the great advantages which Mr. Holroyd Smith had pointed out as being attached to that method of construction.

There was no doubt that the alternative scheme, the barrel or camber road, had been a source of very great danger indeed, and only those persons who were practical road users could appreciate the magnitude of danger. Only a few days ago he was coming along the Brighton road south of Reigate, and for fully two miles he was endeavouring to overtake a taxicab; the reason why this could not be done was that it was absolutely dangerous both for the cab and for his motor car to go on the sides of this particular road on account of the excessive camber. He tried to overtake the cab eventually, but both vehicles suffered some inconvenience and risk. This was only one example of many main roads. It seemed to him that the surveyors who were responsible for some of the roads could not be users of them.

The rotary system of regulating traffic at cross roads to which Mr. Holroyd Smith had alluded seemed to be a likely method of solving a difficult problem, and was worthy of trial.

As to the three-track roads, he believed that there were many roads of that kind. He knew one certainly in which the high-speed traffic was carried in the centre of the road, and the slow-speed traffic at the sides. It seemed to him that this was the only solution of the traffic question.

Mr. W. B. Esson suggested that the Council should communicate with the Road Board and with the police authorities with regard to the advantages of adopting the circular system for traffic in cases where four roads met.

Mr. Ebenezer Howard said that they had such a place at Letchworth as had been described, where four roads met. It was a larger place than Oxford Circus. If the Society would agree to have the experiment tried there, no doubt his Board could arrange it. They could get plenty of vehicles in the immediate neighbourhood. It might be very interesting and could be tried there more readily than in London.

Mr. Davidge said that a very serious objection to the rotary system was that with heavy traffic they would get a perpetual wall of slowly moving vehicles. If they had a single stream of traffic it was excellent, and there could not be a better arrangement, but with two or more rows of vehicles there was complication when one from the inside wanted to cross the outer row to leave the circle. As far as London was concerned the circle would have to be very large indeed, and they would have to enforce a slow single procession, because it would be almost impossible to have two or more rings of traffic.

On a large subject like that which they were discussing it was necessary, as Mr. Howard had pointed out, to have not only the co-operation of engineers and architects, but the co-operation of a very large number of professions indeed. It had been said that architects seemed to be doing all the talking with regard to town planning, and that might be so, but engineers had had a very long innings indeed. For a century or so they had had the whole of the laying out and improvement of towns and suburbs. The official engineer, whoever he might be, would still have the actual execution of the work, and the architect would, he was afraid, come in only as an afterthought. It was absolutely essential, however, if any town planning were to be a success, to obtain some control over the character and elevation of the buildings, and he hoped that this would soon be possible.

In an interesting experiment like that at Letchworth it was possible to control the whole development, and he thought that Mr. Howard had done marvellously well in giving the nation, and he might even say the whole of Europe, such an object-lesson of this kind. One of the speakers had mentioned an example at Beckenham which he had considered rather an improvement on Letchworth. It should be pointed out that that particular area was purely residential, but Letchworth was an industrial centre as well as a residential quarter. They looked to the engineer to bring the architect's flights and fancies down to earth and to combine the artistic and the utilitarian elements in practical form.

As Mr. Matthews had well said, the first essential of town planning was knowledge of local conditions, and the pre-eminent consideration was that the official who laid out the town must, if an engineer, have a knowledge of and sympathy with architecture, and, if an architect, must have knowledge of and sympathy with engineering.

Mr. W. L. Carr said that with regard to the author's specification for making up main arterial roads, he would like to ask at what period of development the author would suggest that this should operate. He assumed that it would not be until after building operations had taken place. If he was correct as to this, he should like to know what the author would suggest as to how much would be required from the estate developer in the first construction of the roads. To carry out the author's suggestion in the first instance would be, in his opinion, a waste of money, and he did not think that the heavy first cost would commend itself to owners. As to subsidiary roads, had the author any objection to, say, 20ft. streets in certain cases, or 10ft. streets round quadrangles which lead off from a 40ft. street? He would also suggest that at a certain distance in carriage ways narrower than 24ft. suitable turning places 24ft. in width should be provided. Further, he would like to hear from the author as to how many houses under one roof he would recommend.

It had been said that there was no mention in the Town Planning Act of the elevations of buildings, but they were told on rather good authority that they would be able to meet that point by including it under the term "Character of Buildings." Under the Ruislip-Northwood scheme they were planning 5,690 acres, and they proposed to schedule 110 acres for factory sites optional, 54 for shops and business premises compulsory, and 200 for shops and business premises optional. On the remainder of the area dwelling houses would be erected.

The **President** said that in some countries there was a very liberal width of road. In Winnipeg, where he had been a fortnight before, the main road was 130ft. wide, with three lines of trams running upon it. The roads running into the country from the main road were something like 90 to 100ft. wide.

REPLY.

The **Author**, replying to the discussion, said, in answer to Mr. Carr, that the roads should be made up according to specification after practically the whole of the buildings in the area, or at all events, the whole of the buildings abutting on the particular road, had been completed. In certain cases a width of road of less than 30ft. might be adopted.

The number of houses under one roof should be limited to two. Mr. Carr did not agree that making a road wider always added

to the value of the property, but he (Mr. Matthews) thought that it seldom happened that that was not the case.

Mr. Brodie had raised a point as to the German method of town planning. This he (Mr. Matthews) preferred to the English method. A corporation in Germany could buy up the land on the outskirts of a town, and lay out their own town planning scheme, selling off what they did not wish to retain. They were, consequently, able to retain sites for monuments, public buildings, gardens, recreation grounds, and so forth, generally without loss to the town. Mr. Brodie said also that it was advisable to buy up land which might be required for future widening of existing roads and allow the occupiers of property abutting upon it to utilise this until the corporation required it. He approved of the land being bought, but did not think private owners should fence in corporation land. The fences would probably be of a very temporary character, and would give the road a most untidy appearance.

He agreed with Mr. Cockrill that many of the local authorities were failing to do as much as they ought under the Town Planning Act for fear of incurring expense. He did not think that he (Mr. Matthews) had set up too high a standard of road-making.

He agreed with the remark that "anyone who had to deal for any length of time with the development of a town saw in the Act a means of saving money to the ratepayers in the health of the town, and in the cost of street improvements which would have been unnecessary if a wise forethought had been used at a time within the memory of persons taking part in the transactions." In the town of Bridlington over £50,000 had been spent in widening roads during the fourteen years that he had been engineer. They had to pull down in one street seventy-three houses, a chapel, and a public-house in order to increase the width of the road from 19 to 50ft.

He was pleased to find that the first speaker in the present discussion was such an authority on town planning as Mr. Ebenezer Howard, the founder of the Garden City movement. Letchworth had been laid out on modern town planning lines, and was a credit not only to this country but to Europe. He agreed with Mr. Howard that the laying out of agricultural land well away from a town was a third type of town planning, but he had confined his paper to the development of existing towns. He also agreed that whatever width roads might be made, provision should be made for the possibility of securing additional land at a small expense for further widening at a future time. He noted Mr. Howard's remark about the grass margin being next to the houses. He observed that in Scarborough and several other towns which he had visited the grass margin was next to the road, and the footpath set inside. The number of houses to the acre for the scheme given in the paper was twelve.

Mr. Holroyd Smith had raised many interesting points, one of which was the cross-section of roads. He had constructed roads both of the camber section and the dished section. One of the chief difficulties of the latter type, was that, if two vehicles were approaching one another in the centre of the road there was a danger of their colliding, as they would be leaning towards one another. This would especially occur with a heavy overhanging top load. Another difficulty, though a small one, was that in a road so constructed the channelling was laid in the centre of the road, and as most traffic on a road was along the centre there was a danger of horses slipping on this. He had had complaints of horses slipping in this way.

A point raised by one of the speakers with regard to the section of a roadway was that water coming off the footpath into the roadway would more readily get away in roads of the cambered type; in a dished road it would have to run to the centre of the road. There were probably other objections, but these occurred to him at the moment.

He agreed with Mr. Holroyd Smith's view that there should be some very definite regulations with regard to the traffic in places where four roads met. The present system of driving in whatever direction the driver chose was unsatisfactory, and he agreed that the circular system as sketched by Mr. Smith would be a very great improvement, and something ought to be done to bring this about.

He agreed with Mr. Brewster that subways were very expensive to construct, and that was why he had recommended that subways should be used only in the case of roads paved with setts on concrete foundation. He did not agree with Mr. Brewster's recommendation that the bed of a road should be rolled in every instance. He agreed with rolling generally, but he had known many cases in which the rolling of the bed of a road while it was being constructed would have been very unsatisfactory. In his own town the roads were constructed chiefly on boulder clay, which was a very spongy material, and it would be a mistake to attempt to roll this. At a place like Southport where the foundation was sand, the roller would very soon be lost in the foundation if much rolling of the bed were attempted.

He agreed with the remarks of Mr. Davidge, as far as they related to the fast and slow traffic. Mr. Davidge referred to the fact that there was no provision made in the Housing and Town Planning Act whereby it was compulsory that architects should send in to a corporation the elevation of the buildings that they intended to erect. At present only plans and sections were sent and the corporation had no opportunity of seeing the elevation of the proposed buildings. He was pleased

to hear from Mr. Carr that the authorities at Northwood would try to enforce the sending in of the elevations of houses.

The suggestions as to the laying out of a town on the hexagonal basis was certainly a very good one, and he would bear it in mind.

The author also communicated the following reply to the written criticisms of the paper.

Mr. J. S. Brodie considers that grass margins, unless well looked after, become untidy and depressing, and he prefers to have the open space probably asphalted or gravelled instead. I see no difficulty in keeping grass margins tidy, it certainly cannot be an expensive item, and I am strongly of the opinion that more of a rural appearance due to wide strips of grass and large numbers of trees is needed in the streets in all residential districts. Mr. Brodie considers that the architectural aspect of town planning must take precedence of the engineering standpoint. I agree to this as far as it relates to a residential area, but in an industrial area the architectural aspect is altogether less important than the engineering.

In reference to Mr. Sydney H. Morgan's notes, I agree with him that the municipal engineer with his local knowledge of the requirements of the town is better fitted to prepare a town planning scheme for a town than the expert engineer who knows little about the district. He does not agree with me that a tar macadam road is the most suitable for the fast traffic roadway leading to an industrial area. I still think that if this road is well constructed on a good foundation tar macadam is a suitable material. I suggested 30ft. in my paper, as the width of the "fast" traffic road, allowing for a single tramway track, but if a double track is required the road should certainly be 5 or 6ft. wider. Where a subsidiary road leads to only a few houses and is a cul-de-sac, the houses being well set back, I agree that a width of 24ft. will be sufficient. Trees planted just inside the private gardens instead of along the line of the grass strip in such a road will no doubt answer the same purpose; but there the difficulty of getting all owners of property abutting on a subsidiary road to agree to this, as it could not be made compulsory.

Mr. F. W. Platt questions my view—to which I still adhere—as to the best position for workmen's dwellings in an industrial town. I agree with him that it is not always necessary when constructing through traffic roads to make them in the first instance 75ft. in width, but land should certainly be reserved so that as soon as the traffic upon the road warrants it, the road may be made the required 75ft.

I am still of the opinion that it is unwise to limit the height of buildings, provided that with higher buildings a greater amount of air space is provided at the back of them.

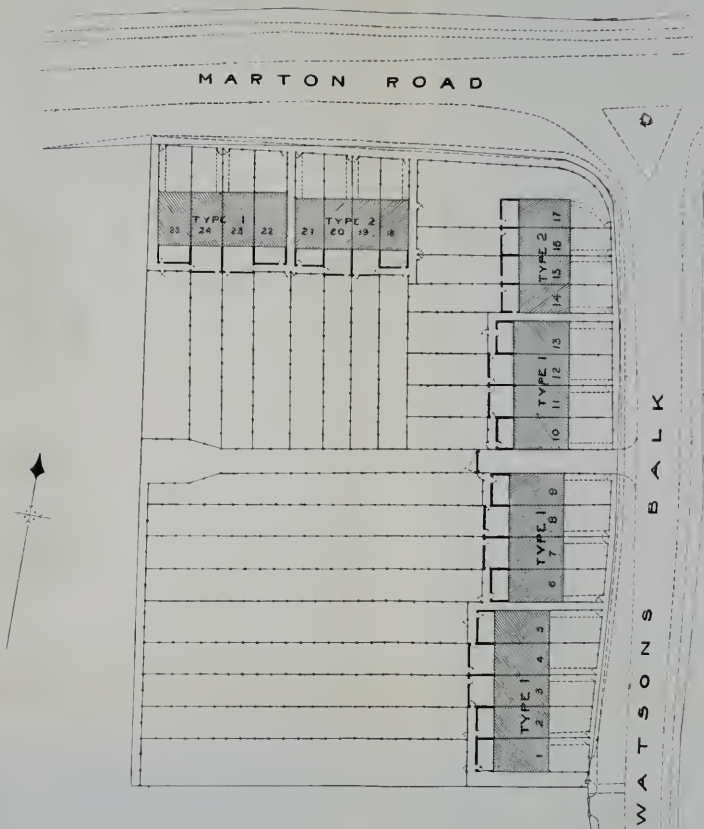
The city engineer of Edinburgh (Mr. A. H. Campbell) has raised several interesting points. I agree with him that not only will engineering and architectural skill be required in the proper development of our towns, but common sense and persuasive force will be equally needed ; that the lay out of the land will depend on its contour ; and that one of the features of a good town plan should be that of obtaining good vistas. In regard to the latter a very great deal might be learnt from the City of Edinburgh where artistic perspectives present themselves at every turn of the road. Mr. H. Gilbert Whyatt raises the question as to whether it is desirable for the local authority of a town, which is practically entirely residential, to limit the erection of works and factories to one particular area in the town, or to exclude them altogether. This is a very important point, and I agree that the law cannot prevent the owner of a house built in a residential area from using this as a workshop with an ugly store yard in connection therewith. As to the subway the author only suggested this in a manufacturing district where the roads are paved with setts on a concrete foundation, and he thinks that some of the difficulties suggested by Mr. Whyatt are only very small ones and could easily be got over.

The author agrees with Mr. Reynolds as to the desirability of rounding corners at road junctions. He admits, however, that these have a tendency to induce motor vehicles to take the corners at dangerous speeds. He does not agree that 35ft. for the main arterial carriageway is insufficient. As to the suggested difficulty of defining the class of vehicle to use the " rapid " and " slow " traffic roads ; there surely need be no difficulty in this matter, as regulations could be framed which would clearly define the two classes of traffic. The objection to Mr. Reynolds suggestion of a triple road, two " slow " roads and a centre " fast " road is that to get on to the " fast " road it would be necessary to cross one of the " slow " roads, and this would be most objectionable, the slow traffic having to be held up to allow the fast traffic to get through.

I agree with Mr. Bowes that the time is fast approaching when in many of our busy towns it will be found absolutely necessary to provide twin roads for fast and slow traffic, as I have suggested in my paper.

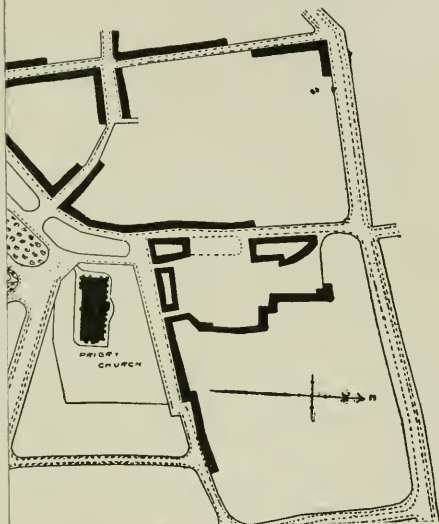
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PLATE I.



THE SOCIETY OF ENGINEERS (INCORPORATED),

October, 1912.



October, 1912.



November 4th, 1912.

JOHN KENNEDY, PRESIDENT,
IN THE CHAIR.

THE GENERATION, AND ELECTRICAL TRANSMISSION OF POWER FOR MARINE TRANSPORTATION.

By WILLIAM P. DURTNALL, M.I.Mar.E., M.I.Auto.E.

THE generation and utilisation of power for the propulsion of ships is an important question, directly affecting the design, construction, and ultimate operating cost of all classes of vessels, and consequently designers are striving to evolve an improved form of hull, combining maximum strength for a given weight of material with minimum frictional resistance for a given speed. Considerable attention has also been given of recent years to the improvement of propeller design and to increasing the thermal efficiency of prime-movers, with a view of reducing fuel consumption. Leaving to the naval architect the investigation of hull construction and equipment, the engineer is concerned with the production of the thrust required to give the vessel the necessary speed with a minimum consumption of fuel.

The fundamental problem of propulsion is to produce economically a sufficient thrust to overcome the resistance met by the ship when moving through water, and there are only two media—air and water—in which this thrust can be produced. With water or any such fluid medium the development of a suitable thrust must depend on the utilisation of the inertia and viscosity of the medium. We know that the production of a change of momentum requires the action of a force and the expenditure of energy, and that conversely the matter acted on will react on the agent, which is producing the change of momentum, such reaction being in fact the resistance opposed to the change of momentum. If there be attached to a ship an agent which will produce a change of momentum in matter of any kind, such change of momentum being directed astern, or at least having a sternward component, this agent will receive a reaction having a forward component, such reaction being then available as thrust for propulsion. For instance, a greater or less propulsive thrust would be given to a boat by a gun firing projectiles over the stern, or by a boy throwing stones in the same direction.

Among the many methods of obtaining this forward reaction, the most simple is that which was used by the Romans for pro-

PELLING their slave galleys, and the idea is still in use at the present day. The Roman oars were broader, flatter, shorter, and lighter than modern ones, and were generally managed by more than one person, the rowers usually facing the bows. They were not moved backwards and forwards as ours are, but inwards and outwards—the action resembling stern sculling rather than rowing—nor did they lie horizontally as ours do, but almost perpendicularly, so that when a vessel was aground, the oars served as legs or props to uphold it. These ancient vessels must have had considerably over-hanging sides to allow of several tiers of rowers working simultaneously. Our method of rowing with horizontal oars somewhat resembles the action of a paddle-wheel; whereas, in the ancient galleys, the sculling action more resembled that of a screw propeller, which is in effect, a continuous sculling machine, the reciprocating movement as used by the Romans being superseded by the revolutions of the propelling blade.

Some doubt exists as to the manner of propelling and steering the ancient galleys, the author's view being that they were both propelled and very efficiently steered by the thrust obtained from the right feathering of the oars under suitable direction, and that consequently no rudders were used. These vessels could swing round almost on their own centres, and this manœuvre was often carried out even when the vessels were practically stationary as regards rudder steering way.

Mechanical power was first applied to propulsion, in 1543, by Blasco de Garay, a Spanish sea captain, who is said to have succeeded in giving motion to paddle-wheels by the use of steam. Various attempts have been made to use the propulsive force of a jet of water, and in 1661 a patent was granted to Thomas Toogood and James Hayes for a method of propelling ships by forcing out water through the bottom of a vessel.

Early experiments and patents in propulsion by mechanical power were those of Robert Hook in 1681, with a feathering paddle wheel, and of Joseph Bramah, an engine maker of Piccadilly, in 1785, with his rotary steam engine, and worm-gear driven stern paddle-wheel, or screw type propellers.

Screw propulsion was, however, practically introduced about 1835, by Francis P. Smith, a farmer, of Hendon, Middlesex. On May 31st, 1836, a model boat fitted with a wooden screw was exhibited in operation on what is now the Welsh Harp pond at Hendon, and was inspected by Sir John Barrow, Secretary to the Admiralty. The results were deemed so satisfactory, that in the autumn of the same year, a boat was built of six tons burden, and about six horse power with a wooden screw consisting of two turns. On November 1st, 1836, she was exhibited in operation on the Paddington Canal, and continued to ply there and on the Thames until Sept., 1837.

In February of that year, an accident showed the advantage of diminishing the length of the screw, about half the length of the propeller being broken away, whereupon the boat immediately quickened her speed, and a higher thrust was produced for the same shaft horse-power.

The sea-going capabilities of the boat were then demonstrated, but before the Admiralty would give a decision they insisted that the screw propeller should be tried on a vessel of at least 200 tons. The *Archimedes* of 237 tons was therefore built at a cost of £10,500, and was fitted with 80 h.p. engines. It was designed for a speed of 4 or 5 knots, which on trials was about doubled.

The Admiralty then decided to adopt the screw propeller in the Navy. Some further experiments were carried out by Mr. Brunel, at Bristol, following which the *Great Britain*, originally built for paddle-wheels, was fitted with a screw propeller, and was the first screw-driven boat to cross the Atlantic.

A number of professional men, at that time did not believe that a steamship, having to carry machinery and coal, instead of using the wind for propulsion, could cross the Atlantic, which goes to show how theory may often be upset by practice; and the theory of some modern engineers, that electrically driven sea-going vessels are impracticable may meet with a similar reverse in the near future.

The engines of the *Great Britain* ran at 18 r.p.m., while the propeller shaft was geared up to 54 r.p.m., the propeller having six blades, and the steam pressure being 25 lb. by gauge. This boat ran fairly successfully under steam from 1843 to 1874, when she was converted into a fully rigged sailing ship.

The gearing between the engine and the propeller was a source of trouble and decreased efficiency, until Smith joined forces with Captain Ericsson, a capable engineer and navigator, who increased the speed of the engine, and direct-coupled it to the propeller. Every credit must be given to those early workers in marine transport, who experienced great opposition from many quarters, and not only had not the advantage of modern machinery, but had to educate navigators, shipbuilders and owners who were not engineers, were opposed to new methods of propulsion, and had very little desire or ability to master the higher branches of either navigation or mechanical sea transport.

Ericsson later went to America, and in 1853 constructed a craft in which one of the boldest attempts was made to find a substitute for steam. This was the *Ericsson*, which had two masts, and ordinary paddle-wheels 32ft. diameter, but no funnels, the machinery being operated on what was then known as the "caloric" principle, which rendered them unnecessary. She was 250ft. long, 40ft. broad, and 31ft. deep, with a gross

tonnage of 1920, and a speed of 12 knots for a consumption of 6 tons of coal per day. She was practically a hot air propelled ship, and Mr. Ericsson was then probably very near to the discovery of the internal combustion engine. To him is also due, the invention of the *Monitor* type of warship, which rendered such enormous service in the American War, this ship being the one which encountered and disabled the *Merrimac* and saved the American Navy of that day from annihilation. To him also, we owe the idea of protecting propellers from hostile shot, and many other ingenious inventions, which entitle him to rank as one of the greatest inventors that the world has ever known.

An interesting attempt to solve the problem of propulsion was that made in connection with H.M.S. *Waterwitch*, an iron-plated gun-boat 162ft. long, 32ft. beam, and 9ft. 9ins. draught, with a displacement of 1062 tons. She was propelled either head or astern by means of two water jets placed close to the hull, and taking advantage of the hull wake effect. The jets were produced by a steam driven 3-cylinder engine, running with the crankshaft vertical, coupled to a kind of rotary pump, which drew water from the underside of the vessel, and delivered a jet at each side. With an expenditure of 750 I.H.P. the speed obtained was 9 knots, this performance being considered very inefficient as compared with a screw propeller, and the scheme therefore dropped. If an effort were made to reintroduce the system to-day, using electric motor-driven turbine pumps, and many more jets, and arranging for the water inlets to be facing the direction in which the boat is proceeding, something might come of it, for jet propulsion possesses the advantage that the propelling apparatus is not only well below water level, but also inside the boat and therefore not easily damaged by projectiles as are other forms of mechanical propellers.

We now come to the *Great Eastern*, which was propelled both by paddle wheels and a screw propeller, had five funnels, was 680ft. long, 82ft. beam, and had a loaded draught of 30ft. The displacement was 27,000 tons, while she had four decks and six masts, with a sail area of 6,200 square feet. Ample attention was given to the provision of bulkheads, of which twelve were transverse and two longitudinal, and the spaces were used as coal bunkers, an idea originated by the genius of Brunel, and copied by the designers of the *Lusitania*, the *Mauretania*, and other modern vessels. The paddle wheels of the *Great Eastern* were 56ft. in diameter, with float boards 13ft. long and 3ft. wide. The screw propeller had four blades, a diameter of 24ft., and a pitch of 37ft. Five boiler rooms were provided to supply steam at a pressure of 25lb. per sq. in. by gauge, the total I.H.P. being about 8,000. She was, however, a commercial failure, for steam engineering had not then reached the efficiency necessary to ensure success. Signs are not wanting now that the size of ships has again reached a point

where, unless a further increase in the thermo-dynamic efficiency is attained, great financial losses will be experienced.

Since the days when Ericsson coupled his engine direct to the screw propeller countless efforts have been made to increase the efficiency of ship propulsion. For instance, the steam engine, instead of working by single expansion, was compounded, which increased the efficiency and reduced the fuel consumption; then followed the triple-expansion engine, which gave further increase in efficiency; progress also took place in the design of hulls, and considerable research work was done with regard to propellers working under various conditions. Great improvements were introduced in the operation and construction of steam boilers, and an attempt was made to introduce the water-tube in place of the fire-tube marine boiler, with a view to reducing the dead-weight, thus again increasing the over-all thermal efficiency of the vessel measured by the number of heat units used per thousand ton-miles at a given speed.

One of the most efficient trials of a cylindrical fire-tube boiler was conducted on the *Saxonia*, kindly lent for the purpose by the Cunard Steamship Company between October 1903, and May 1904. She is a vessel of 14,281 tons, 580ft. long, 64·2ft. beam, and 38·4ft. deep, driven by twin screws and quadruple expansion steam engines, and was at the time considered a very efficient ship. The boilers showed a thermal efficiency of 82·3% with a feed-water temperature of 178° Fahr., and an evaporation of 11·3 lb. of water per lb. of coal burnt, over a run of 13 hours, during which period only six of the 27 furnaces were cleaned. The boiler-room equipment of the *Saxonia* weighed about 1,000 tons, and produced an output of 132,600 lb. of steam per hour, or 132·6 lb. per ton weight of the boiler installation. The total steam consumption per I.H.P. hour was only 13·26 lb., showing that the quadruple-expansion type of engine is very efficient from a thermal, if not from a mechanical, point of view. Boiler efficiency does not seem to have made much, if any, improvement since that date, but great progress has been made in other directions.

Reciprocating steam engines, although greatly improved and brought up to a fine state of efficiency as such, have grave disadvantages, the greatest perhaps, in the case of passenger ships, being the unavoidable vibration, as it is a natural law that a revolving body which is not exactly balanced always runs unequally, and transmits a tremor to anything with which it may be in contact. Large power engines of this type as required in modern high speed vessels of heavy displacement, stand so high in the ship that their cylinders are well above water level; this being a special disadvantage in warships, and no doubt the principal reason why the steam turbine has replaced the efficient reciprocating steam engine in the British Navy.

The measure of the commercial efficiency of a ship in the mercantile marine is roughly the ratio of the dead-weight of freight carried at a given speed, to the amount of fuel consumed in the process. The effective horse-power produced on a ship is measured by the thrust produced in pounds $\times$ vessel speed in feet per minute $\div$ 33,000 = E.H.P. It may be well to mention here that the mechanical equivalent of heat is represented by 778 foot-pounds of work done, this quantity being called a British Thermal Unit. One lb. of say Welsh coal, contains at least 15,000 units of heat, and if this 1lb. of coal is burnt in one hour, it is equivalent to 11,580,000 ft.-lb., or nearly six h.p. An ordinary tramp steamer consumes on an average approximately $1\frac{1}{2}$ lb. of coal per I.H.P. hour, from which it is clear that enormous thermal losses take place daily in thousands of ships.

These losses and their causes may be roughly stated as follows :—

Fuel heat distribution.	
	Per cent.
Heat in gases passing through funnel (some part of this is used for maintaining boiler draught)	20
Surface radiation from boiler	10
Heat absorbed by condenser and auxiliaries..	56
Steam friction in cylinder	2
Steam condensation in cylinder	2
Mechanical friction in engine and propeller shaft	3
Propeller and other losses	3
	96
Thermal propulsive efficiency, <i>i.e.</i> efficiency of propulsion expressed as a percentage of fuel heat	4
	100

That is the equivalent of 100 h.p. in fuel units at the furnaces produces only 4 h.p. of actual propulsive effect, or the "thermal propulsive efficiency" is only 4 per cent.

If a high thermal propulsive efficiency for a given speed and displacement were insisted upon as a standard of excellence a vast decrease in the cost of the sea transportation would be effected, to the benefit of both the shipping trade and the public.

It is well known that a screw propeller to produce a maximum thrust, must run below a certain critical speed, beyond which slip and blade friction losses occur, and cavitation sets in.

The results of numerous trials show that the pressure per sq. in. of projected area is approximately 1lb. for every 1,000ft. per minute circumferential velocity of the blade tips. At full speed and power the pressures seem to be for slow cargo vessels

from 5 to 6lb. per sq. in., for ocean-going mail steamers from 6 to 7lb., for cross-channel boats 7·5 to 8·5lb., for cruisers and battleships 8 to 10·5lb., and in some torpedo craft 9 to 11lb. About 9lb. per sq. in. or rather less is the lower limit for turbine screws and from 10 to 11lb. for fast speed vessels, but pressures greater than about 11lb. per sq. in. seem to give low thrust efficiency. The pressures referred to are estimated mean pressures, as there exists no method of determining accurately the local intensity per sq. in., though it may be assumed in some cases.

Propeller efficiency presents a complicated problem depending on the form and speed of the boat. Small diameter high revolution screw propellers have been found to give much less thrust when the vessel is travelling against a head wind or tide, and such propellers are run close to the speed at which cavitation sets in, so that in case of real necessity for a spurt at high revolution speed to meet certain conditions when entering harbours, etc., there is a very small margin for increase of speed before cavitation sets in. Low speed propellers with their larger blade surface have a greater holding power under the above conditions, with the material advantage of allowing a reasonable increase in revolution speed to meet certain requirements at sea, which are not possible with the high-speed type of propeller.

There is now a noticeable tendency to increase the diameter and reduce the revolutions of the propeller, while the use of twin screws is being advocated in place of triple or quadruple screws for heavy, high-speed vessels. The revolution speed is of great importance in connection with the means of driving the propellers, the fuel consumption and consequently the "thermal propulsive efficiency" of the ship at a given speed.

Until a suitable type of internal combustion engine appears, steam will continue to be used for heavy marine propulsion; its economical generation is therefore of the very highest importance. A gas-fired steam generator shown at the recent Engineering Exhibition, is stated to have a thermal efficiency as high as 90 to 93 per cent., and in the author's opinion the crude and old fashioned methods of generating steam for prime-movers in furnaces, are doomed, and will be superseded by this new and more efficient method.

The experience of sea-going engineers shows that the motive power for driving the propeller should conform to the following conditions :—

- (i.) The driving power must be simply and quickly reversible.
- (ii.) It must be capable of being started and stopped quickly.
- (iii.) It must be capable of being promptly speeded up and down from dead-slow to full-speed, or even in case of emergency be capable of giving out power

sufficient to produce speed above the normal for short periods of time.

- (iv.) It must be capable of being kept running at any desired set speed and of running economically at that speed for very long periods. The "dead-slow" speed should if possible be slower than one-fourth of the normal full-speed revolutions, and in very fast vessels one-eighth or less.
- (v.) It must be capable of working well and reliably in smooth or rough water with the power varying from zero to sometimes more than the normal maximum for short periods, when the propeller experiences rapid changes in resistance to rotation.
- (vi.) It must meet the previous conditions without racing or showing more than say 5 to 8% deviation from the normal set speed, and in the case of heavy rolling, means should be provided to vary the power automatically from port to starboard propellers when operating two or more propellers.
- (vii.) All working parts must be readily accessible for over-hauling and adjustment, and all wearing surfaces must be capable of being easily examined.
- (viii.) The driving machinery must be economical in fuel at all speeds, especially at the normal full-speed at which it is generally run, and the machinery should have the least number of working parts.

Fractures in the tunnel and tail shafts sometimes occur in spite of careful inspection and such an accident is very serious, especially on single screw vessels, and may even lead to the loss of the ship. A ship being practically a flexible girder, the longer the propeller shafts are, the greater the strains set up in them, and this source of danger should be minimised by making the shafts as short as possible. This is done in some vessels, such as cargo boats, in which it is preferred to have the machinery at the stern, to give by its weight sufficient propeller immersion when travelling light, but in passenger boats the boilers and machinery are generally placed forward, so that long tunnel shafts are unavoidable. Electrically driven vessels have the undoubted advantage that the steam and power generating plant may be placed forward, whilst the propeller driving motors may be placed as far aft as the lines of the vessel will allow.

The steam turbine is the most satisfactory prime-mover now in existence for high powers, and will remain so until the gas turbine is developed, especially as the high speed turbine can be made to take advantage of high temperature steam. It also possesses the advantages of light weight and simple construction, has only one moving part, is silent in operation, produces a constant even torque, requires no lubrication in the

steam spaces, and has a high fuel economy, even under tremendously varying loads.

It has, however, important disadvantages; firstly, having to be direct-coupled to the propeller, it must run at a relatively low speed, thus affecting the fuel consumption to a very serious degree; further, the application of the turbine to direct propulsion embodied the idea of raising the speed of the propeller, above its most efficient speed, and this increased the losses at the propeller in developing a certain amount of thrust, which again increased the horse-power necessary to develop it, and consequently the fuel consumption per effective thrust horse-power. This limitation of the number of revolutions demanded increase in the size and weight of the turbine and did not permit of the use of superheated steam; consequently most marine turbines at the present time use saturated steam, which is one reason why the marine direct driving turbine uses about twice as much steam per B.H.P. as one of equal power and higher speed, using superheated steam and high vacuum, in power stations on land.

Further the turbine is not reversible, and consequently in order to have a full power reverse on the shafts it is necessary to instal the turbines in duplicate. Where there are three shafts reversing power has been sacrificed, being provided only on two of the three shafts, and even this power is only a portion of the total ahead power provided on such shafts; and further these so-called reversible turbines are very uneconomical in steam. At the same time practical sea-going conditions require that the machinery shall be live when proceeding, say ahead, at full power and speed, whereas, in that condition the reversing turbines are being run and driven by power from the ahead turbines, thus taking a considerable amount of power which should be used for propulsion. Moreover the extra turbines and pipework occupy a great deal of space and the valve operation for reversing involves waste of valuable time. Even then the reverse is very weak, compared with ordinary marine steam engine driven propellers, for reasons previously given.

A paper by Mr. Thomas Bell, M.I.N.A., designer of the plant for the *Lusitania*, states that when this boat entered the measured mile at a speed of 22·8 knots (the full speed ahead of this boat is about 26 knots), the propellers turning at 166 r.p.m., the engine-room telegraphs were rung for "full speed astern," and nearly four minutes were taken to bring the vessel to a standstill, in which time she ran a distance of three-quarters of a mile, or about six times her own length. If the vessel had been under full draught at 26 knots she would, in the author's opinion, have travelled quite a mile and a half. It should, however, be noted that this vessel has reversing power only on the two inner of her four shafts, which were driven by six turbines. It has been

stated on good authority that had the ship been fitted with modern slow-speed reciprocating engines on, say, three instead of four shafts, the thermal propulsive efficiency would have been increased, and that only 53,000 instead of nearly 70,000 shaft horse-power would have been required to give the vessel the same speed.

The turbine being most efficient at the lower pressure end, what is known as the combination system has been tried on some vessels, including the ill-fated *Titanic*. It consists of driving three propellers at low speed, the two outer ones being driven by reciprocating engines, which exhaust into a low-speed low-pressure turbine driving the centre propeller. This system gives a lower fuel consumption per thousand tons of displacement per mile at a given speed, and better thermal propulsive efficiency whilst going ahead at full power, but even so reversing power has been sacrificed, being available only on the two wing shafts, and in the author's opinion, this method is not as safe and efficient as the system of electrical propulsion which he has introduced under the name of the "Paragon" system. In developing this system a low-revolution speed was decided upon in order to get as much thrust per shaft horse-power as possible, and the question then arose of what method should be adopted for driving the propeller; should it be a steam turbine, reciprocating engine, oil, or gas engine? Limitations were found as regards the fuel consumption, in the application of the turbine, unless some form of gear reduction were used, and on further enquiry it was ascertained that manufacturers here and on the Continent were not in a position to guarantee such mechanical gears to run always silently as required.

Without a complicated system of change-speed and reverse gears and clutches it would have been essential to regulate the speed of the turbine, and to put in another turbine to give a full power reverse, and thereby to ensure safety at sea, especially on a heavy ship at high speed. On approaching the question of using reciprocating steam engines, with forced lubrication and superheated steam, many difficulties were met, especially those common to all heavy reciprocating masses in motion, and the losses were still considerable. Almost the same applied to the internal combustion engine, with the further serious defect that on account of the compression this engine could not be run at a suitable dead-slow speed. With a heavy oil engine at slow speed complete combustion could not be effected, and cylinder deposit would have taken place, which, in addition to other considerations, forbade the use of the direct-coupled internal combustion engine for this system of ship propulsion.

Knowing that, if necessary, it would be possible to design and construct electric motors which would run equally efficiently in either direction with a speed range from zero to maximum with

variable voltage, the continuous current system then came under consideration, and was favourably viewed because such motors are self-starting and develop a heavy torque at starting, which is a considerable advantage if it should be necessary to reverse the propeller when at full speed ahead.

Having gained considerable knowledge, in connection with petrol electric motor cars, of the trouble that might be experienced with the continuous current system, attention was next directed to the polyphase alternating current method, in which the troubles of commutation and other difficulties were wanting, and a scheme was prepared on these lines, in respect of which patents were granted in nineteen countries in 1905. The system as then laid out has now been installed by the General Electric Company of America on the U.S. twin-screw collier *Jupiter*, of 20,000 tons displacement and about 6,000 horse-power. The turbine will run at 2,000 r.p.m., and by putting more poles in the motors than in the generators electrical speed-reduction gear can be formed so that the maximum thrust can be secured with slow-running screw propellers, thus reducing the shaft horse-power required. Thermal losses naturally take place in transforming the mechanical power of the turbine into electrical power, and then transforming this back at slow speed in the motors into mechanical shaft horse-power, but shop tests indicate that the steam consumption per shaft horse-power at sea will be about 11·25 lb. per hour, which is 20 per cent. less than her sister ship the *Cyclops*, of the same tonnage and approximately the same designed speed.

It is probable that an even higher speed than that estimated will be attained, or that the steam consumption for the same speed will be lower, on account of the saving in weight of machinery. The weight of machinery in the steam-driven boat is 280 tons, whilst that of the electrically propelled ship is only 156 tons, and with the same dead-weight of freight, less displacement will be shown.

A third vessel named the *Neptune* is under test in America, and is driven by twin screws, and with what is called a geared turbine, as advocated by the Westinghouse Company of America. The mechanical method of speed reduction in large powers is limited. Propellers are to be run at, say, 135 r.p.m. in the case of the *Neptune*, the turbine revolutions being only about 1,250, a contrast with the electrically driven vessel, in which there is practically no limit to the speed at which the turbine may run. On the *Jupiter* the normal speed is 2,000 r.p.m., the turbines being lighter and less costly, with a better thermal efficiency, and consequently a lower steam consumption per horse-power hour, than the geared turbine installation. The full particulars of the *Neptune* trials have not yet come to hand, but the turbine speed was 1,250 r.p.m., and that of the propeller

135 r.p.m., and the trials showed a performance much inferior to that of the *Cyclops*. It can therefore be assumed that mechanical reduction of speed is here out of the question, although attempts have been made to alter the turbines and propellers, but unless the ratio is made as large as that of the *Jupiter*, namely, 18 to 1, instead of the $9\frac{1}{4}$ to 1 of the *Neptune*, the latter can never be so efficient, and any improvement in the design of its turbines or propellers can be equally applied to the electrical boat, which will then still hold an advantage in respect of thermal efficiency in addition to all its other merits.

The turbine not being reversible, separate reverse turbines have to be installed, thus adding to the weight; further, the stress on toothed gearing increases with the shortening of the teeth in the pinions, and this limits the practicable gear reduction ratio. On the other hand the length of the pinions and wheels is limited by the torsional elasticity of metal, and disaster might occur by reason of unequal distribution of the tooth load through the tooth length. The shock and strain developed in teeth is increased by raising the peripheral speed, and this again limits the turbine speed for a given pinion diameter and power. Increased diameter and larger power in gears produce vibration and noise which are likely to be noticeable in distant parts of the ship, and to cause certain defects. To gear the turbines to the propeller shaft means that the boiler equipment must be in close proximity thereto and therefore either that the weight must be well aft, or that thermal losses must occur in the transmission of steam from the boilers to the turbines, while other drawbacks are to be anticipated.

The system installed on the *Jupiter* is being fitted up in the manner advocated by the author with a reduction ratio obtained by providing the generators with a less number of magnetic poles than the motors, while in order to start the motors from standing, and to develop sufficient torque to reverse the propellers when necessary, the rotors of the induction motors have been fitted with slip rings. The current is generated at practically constant frequency and voltage, which although working well in the present instance, with two 3,000 h.p. motors, might conceivably cause serious trouble in very large powers, as in the case of liners and battleships, where the power may be as much as 25,000 h.p. per shaft. With this in view the author carried out some experiments which proved the value of the induction motor known as the squirrel cage motor, a device which is an important factor in the successful propulsion of ships by electricity, and meets with the approval of many practical marine engineers.

This squirrel cage motor is the most efficient motor in existence and like the turbine has only one moving part. Its very simple design and construction, combined with its great

mechanical strength is likely to bring it into high favour for electrically propelled vessels : it has no slip rings or brush-gear, the whole of the current in the rotor winding being induced across one air gap, which is a tremendous advantage, especially with large powers. This motor has no sparking limit, as is the case in all contact conduction machines, consequently the output in mechanical horse-power per unit weight is much higher than in any other type of electrical machine, with gain in efficiency. A very large section is given to the windings of these machines, which together with the fact that the windings are arranged so that copper losses are not localised, and that iron of a laminated character is used in the construction of both rotor and stator, gives every facility for ventilation. Burnt out armatures and the turning of commutators are the bug-bears of all engineers operating heavy electrically driven machinery but these defects are almost unknown in the case of the squirrel cage motor. Its only fault, and the reason why it is not generally used throughout the world, is the fact that at the time of the author's first investigations, it was not able to start on load, or to produce even sufficient starting torque in large powers to start itself light. When standing, and being supplied with high frequency current it acts only as a short-circuited alternating current transformer. If the difficulty of starting could have been overcome this motor offered an ideal method of driving propeller shafts for ship propulsion.

In 1908 the author took out patents in many countries for a method of generating current at variable frequency and voltage, and under these patents was evolved an efficient squirrel cage motor. At starting a very heavy torque is developed by such motors if they are supplied with a much lower frequency current than is used for running them at top speed and full power, and cumbersome and wasteful water or other resistances are not required either for reversing or speed regulation ; moreover only three leads or cables are required between the controller and the motors, and the weight of the motor per unit power is low, while the heat losses are less, thus adding little to the heat of machinery rooms below water level. The working current from the generators is supplied only to its one part, which is stationary, so that no rubbing contacts of any kind are required, and the motor can work in almost any position. It has only one winding and the winding space is very small, consequently the teeth are short, and there is a highly efficient magnetic circuit. If supplied with lower voltage as well as lower frequency, the magnetising currents are reduced, and the motor will run for months on end, with high efficiency, at practically any speed and power, while the first and running costs are low. These are some of the reasons for the adoption of this motor in connection with the Paragon system of ship

propulsion, as there exists at present no other so simple and strong a mechanical machine for driving propellers, as well as auxiliary machinery of all kinds.

This motor meets all the conditions laid down on page 272, and as regards the method of supplying current the polyphase alternating current system has been found to answer the purpose most satisfactorily.

The use of electricity for the propulsion of large ships, was a matter which had to await the advance of engineering science and the production of suitable prime-movers, and a few years ago the proposals could not have attained a commercial success, but, to-day with the steam turbine, the internal combustion engine, and in the very early future the gas turbine, the means are at hand for driving the generators to produce current for the use of the shaft driving motors. Ship propulsion by electricity therefore, has been until quite recently looked upon by many engineers, who have perhaps not had cause nor inclination to investigate the problem, as impossible. Generally speaking, marine engineers and naval architects have not kept pace with the great advance of recent years in heavy electrical power engineering, and consequently they could not appreciate any persistent attempt to solve the problem. On the other hand, electrical engineers are largely unacquainted with the intricacies of naval architecture and marine engineering such as the question of screw propeller losses when run at high speed. Until quite recently it has been maintained that a high speed propeller was as efficient in producing thrust as a low speed one, and so the propulsion of ships by electricity made no advance, many electrical engineers openly condemning the scheme as uncommercial.

Great credit is therefore due to Admiral Cone of the U.S. Navy and his colleagues, who have in hand the equipment of the *Jupiter* on behalf of the American Government, and also to Mr. W. L. R. Emmet, of the General Electric Company of America, the designer of the plant for the *Jupiter*. Mr. Emmet is also the chief turbine engineer of the above company, who build the direct-coupled Curtiss turbine, and consequently his knowledge of both methods of propeller driving makes all the more certain the fact that the general adoption of electrical power for ship propulsion is nigh at hand. Mr. Henry A. Mavor is also engaged on the equipment of a 600 h.p. electrically driven ship, on the lines indicated, but, in this case the prime movers are two 300 h.p. Diesel engines running at 400 r.p.m. and supplying three phase alternating current to one squirrel cage induction motor driving the propeller at 78 r.p.m.. This ship will undergo her trials at approximately the same time as the larger *Jupiter*, the results of which will be awaited with interest. It must also be mentioned that Mr. A. J. Maginnis, M.Inst.C.E., of Liverpool, as far back

as 1909, entered into a contract for the conversion of a large ship on the Paragon system, but the matter fell through for reasons beyond Mr. Maginnis' control.

Much interesting research work and design has been done by Dr. Hele-Shaw and Mr. Holzapfel in this country, and by Dr. Fottinger in Germany, with regard to hydraulic power transmission between the high speed non-reversing prime-mover and the reversible and efficient low speed propeller, and the author recently inspected a most interesting exhibit by Dr. Hele-Shaw at the Engineering Exhibition, and also saw his steering gear in use, both in this country and at Trieste, in Austria, where it is giving great satisfaction.

There are not lacking signs that British shipping is feeling the competition of other countries, which are introducing new and more efficient means of propelling ships. The actual ships in hand, and the papers that have recently been read before American and Continental societies of naval architects and marine engineers show that the electrically driven ship has now become a matter of more than academic interest. The successful results which may be achieved by the *Jupiter* may even change the naval programme of more than one Great Power, and it is to be hoped that the British Government will take a wide and unprejudiced view of the real position which has been created.

(A series of lantern slides was shown on the screen, including the illustrations given in the Appendix to this paper.)

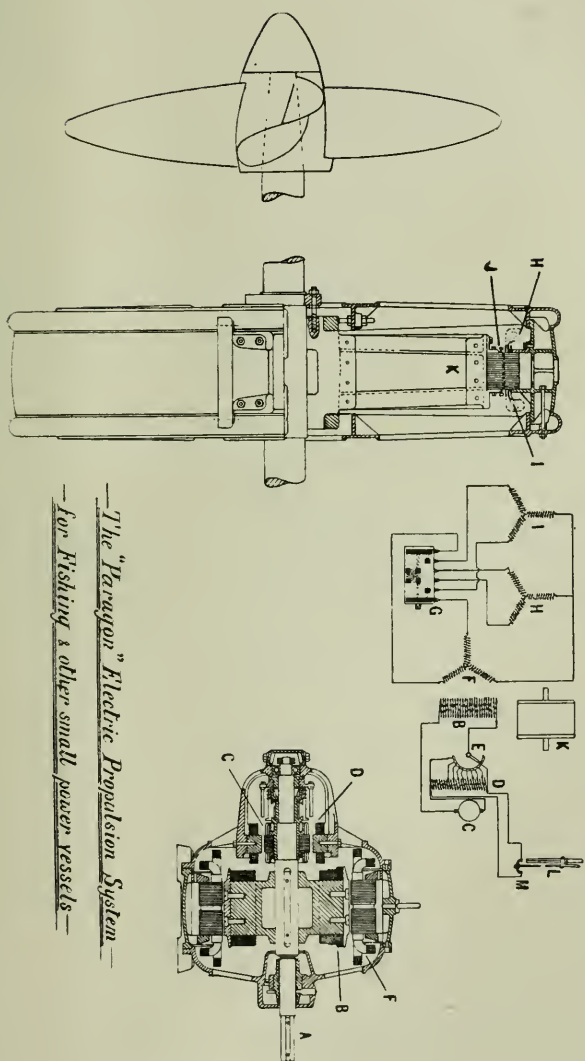
APPENDIX.

FIG. 1.

The "Paragon" system applied to small craft and as the auxiliary power on sailing yachts.

The engine is direct-coupled to the generator shaft A, on which is mounted the revolving field magnet B, and the armature of the continuous current exciter C, which together give the necessary flywheel effect to the engine. The exciter field magnets D are series wound in sections for varying the excitation at low motor speed, and so reducing the magnetising current. This regulation is effected by hand or automatically by means of the regulating switch E which cuts out sections of the field windings. Three-phase, polyphase alternating current is given off the windings F from the fixed armature of the generator and no main current is carried by revolving members of either the induction motor or the generator. Two speeds are given on the motor with constant speed on the engine and generator, and are controlled by the contact maker G, the current being delivered to the windings H, or I, as desired. With an engine speed of 800 r.p.m. and a maximum propeller speed of 200 r.p.m., the generator would be wound for 2 poles and the winding H nearest to the air gap on the motor, would be wound for 8 poles, the winding I being wound for 16 poles. This would give the motor two synchronous speeds of 200 and 100 r.p.m., either ahead or astern, with the engine always running in one direction. J is the squirrel cage winding in the motor rotor, and K is the rotor itself, which is mounted on and coupled to the propeller shaft, the thrust block not being shown. The whole control is effected by the handle L, fixed on the squared shaft on the contact maker G. This handle engages, by the trigger attached to it, in slots on a change speed indicator not shown. The change of connection is made under "no-voltage" conditions, as by disengaging the handle, the contact M short-circuits the series field of the exciter. The change of connections is made, and the trigger let go, uncovering the contacts M, when the voltage on the exciter and the system generally gradually rises to the maximum. The control may be in the engine room, or on the bridge.

This method has been in successful operation on the author's motor omnibuses here and on the Continent, up to 40 horse-power, and is recommended for main propulsion or auxiliary power in vessels up to about 100 h.p., above which more than two set speeds are desirable. In a recent scheme for the propulsion of a twin screw barge on the Thames the 45 h.p. engine, running at 1,000 r.p.m., drives twin screws at 200 r.p.m., by means of two 17 h.p. induction motors, the over-all transmission efficiency being 76 per cent.



—The "Harvagon" Electric Propulsion System—
 —for Fishing & other small power vessels—

FIG. 1.

FIG. 2.

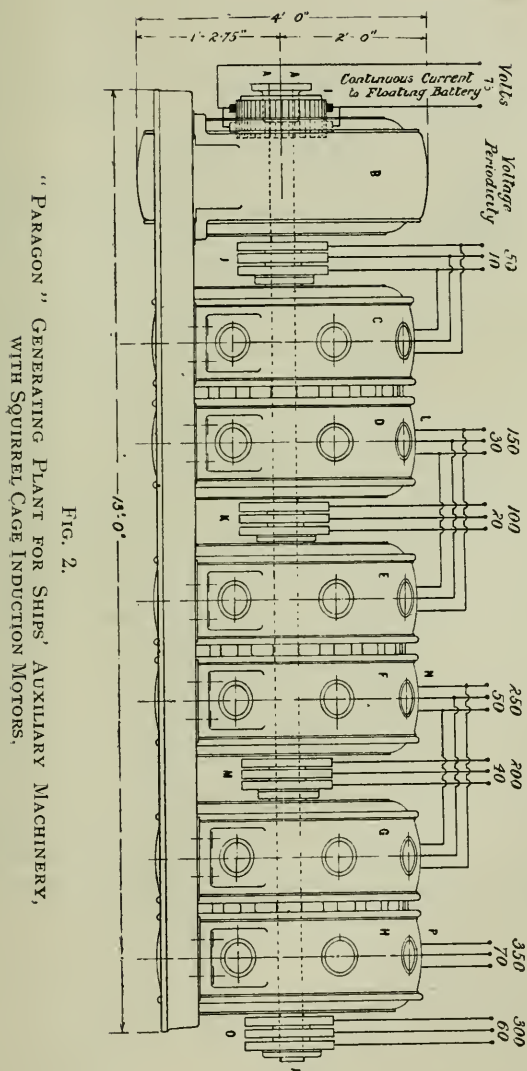
The "Paragon" system of driving auxiliary machinery on ships.

The system here shown comprises the simplest and most reliable machinery requiring the minimum of skilled attention. It was designed by a large British firm for operating the propelling and dredging machinery, the electric lighting, and the auxiliary machinery on a dredger, and was to be driven by a 300 h.p. Diesel engine running at a constant speed.

A is the power shaft driven by the engine, and extending through the whole set of machines, driving them all at 300 r.p.m. B is the prime-generator, wound for 4 poles, with an armature giving both continuous and three-phase alternating current, the former at a pressure of 75 volts, while the slip-rings J at the other end give off polyphase alternating current at 50 volts and 10 periods per sec. There is a small "Edison" type storage battery balanced across the terminals of the D.C. side, to take any discharge from the motors when they regenerate, and to supply current for lighting, wireless, or other purposes.

C is a transformer-generator having a fixed primary member, and a mechanically driven secondary member wound for 4 poles. In both primary and secondary members, the 10 period current is tapped and part of it is sent into the primary winding of the transformer-generator C, the resulting magnetic flux revolving in the opposite direction to that in which its secondary member is being driven by the engine, so that the winding on the secondary is excited twice for every mechanical revolution, once by the mechanical turn of the engine, and once electro-magnetically by the 10 period current revolving in the primary member of C. The resulting current at 100 volts and 20 periods is tapped off the winding of the secondary of C, and is taken by leads to the slip-rings at K, from whence it is conveyed to the motors.

At the same time tappings are taken off the leads, so that some of the 20 period current is taken into the primary windings of the transformer-generator D. In this case the primary member is mechanically driven by the engine, and the magnetic flux revolves in the direction in which the primary is driven by the engine, the stator secondary member of this transformer-generator being wound for 4 poles and excited three times per revolution of the engine, once by the mechanical turn and twice by the electro-magnetic flux revolving in the iron of the primary member, so that polyphase alternating current at 150 volts and 30 periods is delivered at the terminals of transformer-generator D. Some of this current is taken into the transformer-generator E, and then successively through the transformer-generators F, G, & H, producing in each case an increase of 50 volts and 10 periods, so that finally a current at 350 volts and 70 periods is taken off from the stator windings at P.



Motors driving machinery on the ship.

These motors are designed with squirrel cage rotors, the primary members of which are wound for 350 volts, the starting and reversing, etc., being effected by controllers (or frequency selectors). To start a motor, the controller is put on the first of the seven stops, thus connecting the winding on the motor to the 50 volt, 10 period current from the slip-rings J, the motor starts, and assuming that it is wound for 10 poles, its synchronous speed will be 120 r.p.m. By moving the controller on to the second and subsequent stops, the speed of the motor is increased by steps to its maximum of 840 r.p.m. No wasteful resistances are used for accelerating the motor, and every watt generated is utilised for power. When driving machines such as cranes, the motors, after being run at full speed to lift the load, are stopped by moving the controller back to the zero position and in passing the various stops, the frequency in the primary members of the motors is continually changing, the rotors acting on the stator or secondary so that they momentarily act as generators, and so send current back to the mains, this representing the kinetic energy in the moving mass of the stopping load and motor. The load being stopped, the crane swung round, and the motor reversed, the load falls at a given speed decided by the frequency supplied to the motor. The load also drives the rotor slightly above the synchronous speed of the magnetic flux in the stators, so that lowering the load generates current which is delivered to the mains at any frequency, and may either be used by other motors, thus easing the prime-mover and saving fuel, or may find its way to the prime-generator B, and out of its D. C. end into a floating battery.

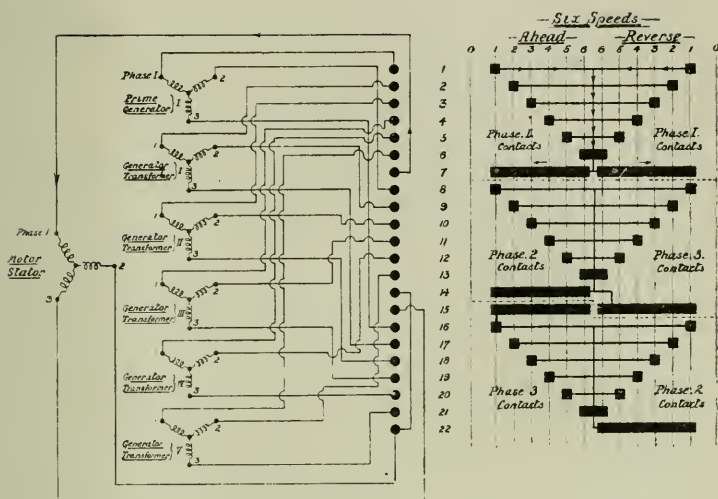


FIG. 2A.

"PARAGON" REVERSIBLE POLYPHASE INDUCTION MOTOR CONTROLLER.

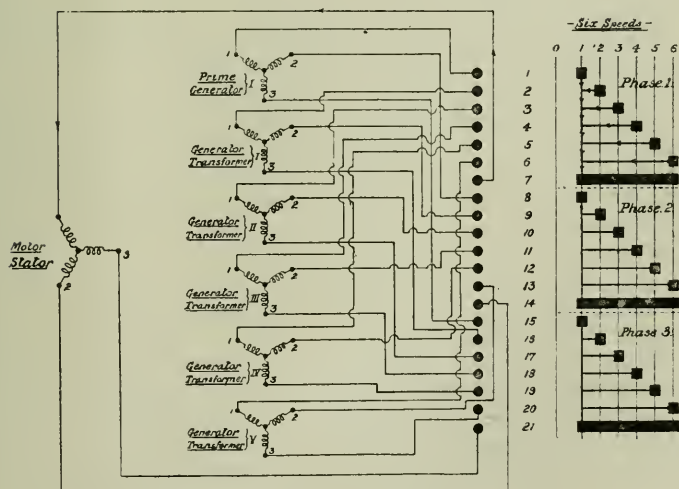


FIG. 2B.

"PARAGON" NON-REVERSIBLE POLYPHASE INDUCTION MOTOR CONTROLLER.

FIG. 3.

The "Paragon" system applied to marine propulsion and railway traction, with 500 h.p. internal combustion engines as prime-movers, running at 500 r.p.m.

DESCRIPTION OF SPEED-CONTROL.

FIRST SPEED.—A continuous current exciter is put on the slip-rings of the revolving field-magnet of the 8 pole prime-generator B, and a three-phase current of 33·3 cycles per sec. is delivered to the slip-rings on the primary member of the transformer-generator C.

The direction of the current in the windings of the primary member of C is such that the resulting magnetic flux revolves in the opposite direction to that of the rotor. Since the rotor is wound for only 4 poles as against 8 of the prime-generator B, and they are both on the same shaft, the magnetic flux revolves backwards twice to every forward revolution of the rotor core. Consequently the secondary winding on the stator of the transformer-generator C delivers a three-phase current at a periodicity of 16·7 cycles per sec. A 56 pole motor thus supplied runs at about 34 r.p.m. and is direct-connected to the propeller shaft ; consequently the first speed of the screw is about 34 r.p.m.

SECOND SPEED.—To increase the speed, the excitation is switched off the generator B, and whilst under no-voltage conditions, the controller effects connections by which the motor is supplied direct from the generator B, which is then again excited, and current at 33·3 cycles per sec. supplied to the motor, causing it to accelerate to about 65 r.p.m.

THIRD SPEED.—The third speed is obtained by so changing the connections (again under no-voltage conditions) that the current from the generator B is again sent into the transformer-generator C (but in the opposite direction to that employed to get the lowest speed) by reversing two of the three supply leads between the generator and the mechanically driven primary member of the transformer-generators.

As a result, the magnetic flux set up in the rotor of the transformer-generator has twice as great a periodicity per revolution of the engine as would be the case were the flux set up by a stationary primary in the usual way. This may be expressed by stating that there is a mechanically-imparted frequency superposed upon an electro-magnetically imparted frequency. The aggregate result is that the 4 pole stationary secondary winding of the transformer-generator C, supplies to the 56 pole motor a periodicity of 50 cycles per sec., made up of (a) a periodicity of 16·7 cycles per sec. mechanically imparted by the engine through the rotor of the transformer-generator C, and (b) a periodicity of 33·3 cycles per sec. electro-

magnetically imparted and supplied from the 8 pole prime-generator B. The 56 pole squirrel cage induction motor then drives the screw propeller at about 97 r.p.m.

FOURTH SPEED.—The three lowest speeds are useful for vessels in foggy weather, when coming out of harbour, etc., and for warships travelling at cruising speed. At such speeds, the power required from the induction motor is small, and the load factor of the plant smaller, but the economy of the engine is higher when running at its normal speed of 500 r.p.m., than would be the case without the electrical apparatus, for then it would be necessary to reduce the engine speed in order to lessen the speed of the vessel. Such reductions in the speed of internal-combustion engines are inconsistent with fuel economy.

To reach the fourth speed the connections on the prime-generator B, and the transformer-generator C, remain as for the third speed, but the current from the secondary member of the transformer-generator C, before being taken to the induction motor, is sent into the "mechanically driven" primary member of the second transformer-generator D. The latter has 4-pole windings on both primary and secondary members, and since the rotor or primary member is driven by the engine at say 500 r.p.m., the windings of the stator secondary member deliver a 66·7 cycle current; three-fourths of the periodicity being imparted "electro-magnetically" by the current from the B and C machines, and one-fourth "mechanically" due of the speed of the rotor of D, the electro-magnetic flux revolving in the rotor core in the direction in which the latter is driven.

When this 66·7 cycle current is carried to the 56 pole induction motor on the propeller shaft, the latter revolves at about 130 r.p.m. The power is greater (since more is required to overcome the resistance of the vessel through the water—roughly as the cube of the vessel speed) but the three machines B, C, and D, are all at work, and automatically draw more mechanical power from the engine. The engine, however, will be running at its most efficient speed of 500 r.p.m., the load being approximately 75 per cent. of full load.

FIFTH SPEED.—For the fifth (*i.e.* the highest) speed the connections are so modified that the current from D is sent into the primary (*i.e.* the rotor) windings of E, and a current of 83·3 cycles per sec. is sent to the 56 pole induction motor from the secondary (*i.e.* the stator member) of the third transformer-generator E. This generates the highest voltage, current, and frequency, and consequently all four machines are at work, taking full power from the engine.

The 56 pole squirrel-cage induction motor will then accelerate to about 160 r.p.m., and the vessel proceeds at top speed under full power, each of the four generating machines drawing about

150 h.p. from the engine, which distributes its power between them.

REVERSING.—Although full-power is not required for going astern, a very large torque is required in reversing a screw propeller, especially with the vessel at full speed.

In the "Paragon" system, squirrel cage motors are employed because of their simplicity, efficiency, and small weight per h.p. at a given speed. In order to develop torque for starting or reversing, a low frequency (say 16·7 cycles per sec.) is turned on to the motor, instead of the 83·3 cycles used for the highest motor speed. To reverse for stopping or going astern, the controller is brought to the reverse position, so that connections are made as for the first speed ahead, but two of the three leads to the motor are reversed, and pass the 16·7 cycle current to the primary member of the stator of the 56 pole motor, producing a magnetic flux, which revolves backwards. The voltage will be only about 20% of that required for full speed; energy is saved and the current excites the short-circuited secondary member of the rotor, momentarily producing a heavy current in the winding, this acting as a powerful brake on the motor. Consequently the propeller stops, begins to reverse, and very quickly runs up to a speed of about 34 r.p.m. in the opposite direction.

If the vessel be going full speed ahead, and the ahead motor torque be taken off (as it would be when the exciter is taken off the generator B whilst the connections are being changed by the controller) the propeller will be acting as a prime-mover driving the rotor of the motor in the ahead direction, because the momentum of the vessel is still directed ahead, and the propeller is being dragged through the water. The pressure is then on the front of the propeller blades, and therefore the motor rotor is still being turned by the propeller in the ahead direction, but as soon as the connections are made and the exciter again put on to the prime-generator B, the magnetic flux in the core of the motor stator F will revolve in the opposite direction while the propeller is being stopped. When the current is again applied the propeller blades are held stationary, and consequently the vessel slows down. The current being on in the reverse direction soon overcomes the ahead torque on the propeller, and the rotor turns and accelerates in the astern direction. The vessel having meanwhile come to rest, begins to go astern until the first speed astern is reached. Other astern speeds can be obtained, the engine always running at one speed, or if desired the engine speed can be slightly varied, so that practically any speed can be given to the propeller.

MARINE TRANSPORTATION.

JOURNAL OF THE SOCIETY OF ENGINEERS (INCORPORATED),

November, 1912.

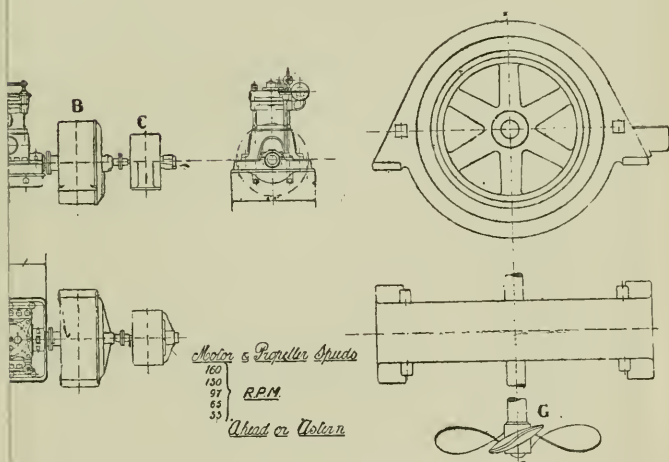


FIG. 3.

ON " SYSTEM WITH DIESEL ENGINE.

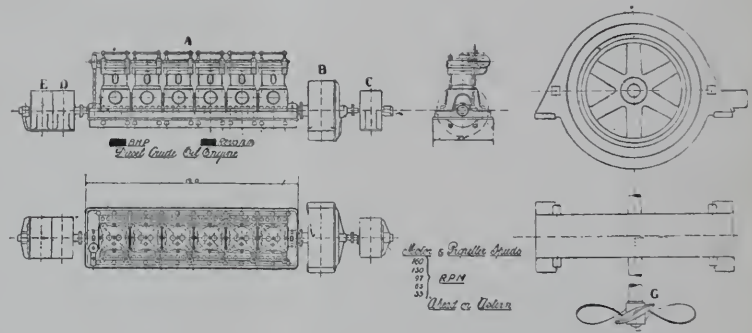


FIG. 3.

"PARAGON" SYSTEM WITH DIESEL ENGINE.

(In another layout of the "Paragon" system, it is possible to bring the frequency up from zero to maximum, with the engine always running at the top speed, so that induction motors may be run at any speed without jump from zero to maximum).

Dividing the number of prime-movers.

The system also allows of several prime-movers being used to drive the different prime-generators and transformer-generators. Thus four 125 h.p. engines (one to each machine) might have been used, instead of one 500 h.p. engine to four machines. By this plan, with the boat at "second" speed, only one engine (that driving the machine B) will be required, but this engine will run at full speed, and with its greatest fuel efficiency, while the propeller will then run at 65 r.p.m. or about 0.41 per cent. of full speed.

This gives the advantage that both the engine, the generator and (by reason of low voltage and frequency) the induction motor, will be working with the minimum amount of fuel per 1,000 displacement ton miles at that speed. This is a very important consideration for a warship, which has to travel at a cruising speed of about 14 or 15 knots, as against a full speed of say 25 or more knots. These variable speed-torque conditions are obtained with the highest thermal efficiency, as no resistances or other power-consuming devices are used or required. The application of the squirrel cage induction motor is thus possible, giving a great mechanical advantage. There are many ways of laying out the "Paragon" variable frequency and voltage system to suit various conditions and types of vessels.

FIG. 4.

Layout of the plant that is being installed on the American Navy Collier *Jupiter*, the first high power electrically propelled ship ever built. She is one of three sister boats each of 20,000 tons displacement, with a dead load carrying capacity of 12,000 tons of coal or 375,000 gallons of oil fuel, for use in American battleships, etc., and is to run at not less than 14 knots. The machinery is on the system advocated by the author in this country for many years. The power plant consists of one six stage "Curtis" steam turbo-generator, running at about 2,000 r.p.m., and driving a two-pole three-phase alternating current generator delivering current at about 2,000 volts to two wound rotor polyphase alternating current induction motors, each having 36 magnetic poles, the reduction in speed ratio being 18 turns on the turbine to one on the motors, the latter being designed to run at approximately 110 r.p.m. at full power and vessel speed. The hull was designed by Naval Constructor Robertson, while the machinery is being installed under Admiral Cone (Chief Engineer U.S. Navy) and has been supplied by the General Electric Company of America. The turbine and electrical machinery is to the designs of Mr. W. L. R. Emmet, of New York.

Steam enters at A into the turbine B, through an ingenious system of multiple jets, by which a high efficiency can be obtained at constant speed and light load. The turbine drives the three-phase synchronous generator C at 2,000 r.p.m., generating current at approximately 2,000 volts. The current flows through control switch gear to two wound rotor induction motors D and E, fitted with slip-rings H, for the insertion of resistance (not shown) to take up the surplus electrical energy when starting and reversing (as in this case the current is generated at constant speed with a given voltage and frequency). The speed reduction ratio is 18.2 to 1, and intermediate speeds are obtained by reducing the number of revolutions of the turbine.

The reaction from the propellers G, G, is taken on and delivered to the hull by the thrust-blocks F, F.

The effect of the variable thrust produced when the vessel rolls will also be of interest. Owing to the two induction motors being coupled electrically through the generator, the result will be that when the propellers are unequally immersed, the current not required by the motor of the more lightly immersed propeller, will be automatically delivered to that of the more deeply immersed, thereby decreasing the torque of the former and increasing that of the latter, and thus not only avoiding racing, but also preventing the deeply immersed propeller from slowing up; consequently the thermal propulsive efficiency in these conditions will be greater than in any other system.

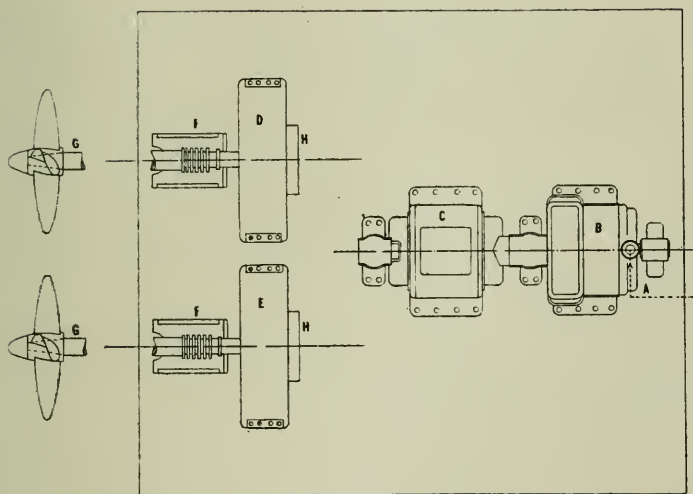


FIG. 4.

"PARAGON" SYSTEM ON U.S. COLLIER *Jupiter*.

FIG. 5.

Shows diagrammatically a proposition recently made to the American Government for electrically propelling a battleship of 28,000 shaft h.p. Steam enters two machinery rooms, each containing one turbine B, a polyphase alternator C, two induction motors D and F, and a thrust block G taking the thrust from the propellers H,H.

The chief interest is the regulation of the propeller speed, especially at half speed, which is accomplished by changing the number of magnetic poles in the squirrel cage induction motor F, and by a change-over switch (not shown). The windings are put in series instead of in parallel, so that the propeller is then, with the same frequency, driven at only half speed, the power required being only about one-fourth of that for full vessel speed. One of the turbines is therefore closed down, and the other supplies the current, at full turbine speed and about half load. Reversing is effected by the motor D. The slip-ring case E, contains slip-rings provided with resistances to take the surplus electrical energy, and by this means the propeller shaft can be started up at any time.

The output of each of the two turbo-alternators is 10,500 k.w., the power transmission efficiency being estimated at 92% thus giving 26,000 shaft h.p. at about 232 r.p.m., whilst the turbine generators were designed to run at about 1,172 r.p.m.

Admiral Cone, the chief engineer of the U.S. Navy, has stated that he believed such units, fitted with pole-changing devices on the two motors, would produce an economy very close to the maximum obtainable, and that both he and the officers of the Bureau of Steam Engineering were convinced that electrical reducing gear was superior to mechanical gear in general efficiency of transmission.

Only two turbines are required in this application, whereas in the ordinary layout of direct-coupled turbines, as many as ten turbines may be required.

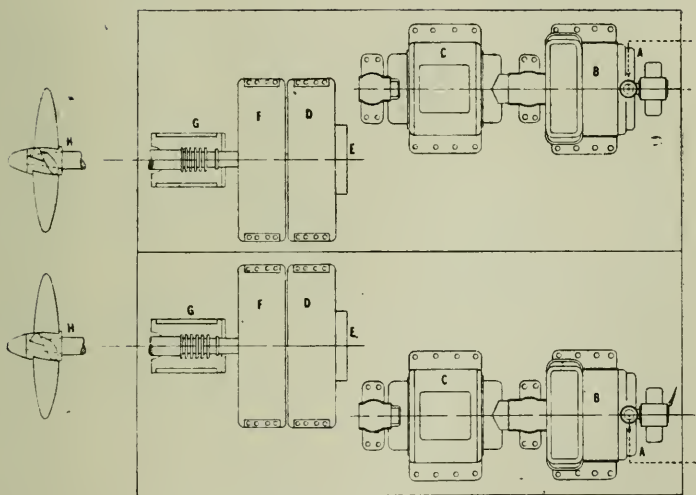


FIG. 5.

"PARAGON" SYSTEM AS PROPOSED FOR 26,000 H.P. BATTLESHIP.

FIG. 6.

Shows diagrammatically the usual method of driving the four shafts of a turbine driven battleship of 28,000 shaft h.p. at 300 r.p.m. There are no fewer than ten turbines in this scheme, viz.—

2 main 'ahead' turbines, 2 low-pressure 'ahead' turbines, 2 high-pressure 'astern' turbines, 2 low-pressure 'astern' turbines, 1 high-pressure 'cruising' turbine, 1 medium-pressure 'cruising' turbine.

The low-pressure 'astern' and 'ahead' turbines are in the same cases, so that there are only eight units for the ten turbines.

The steam pipe connections and valve control are somewhat complicated, and offer large surface to radiation. Reversing power, but, not full power is given on all four shafts, and the steam economy is very low when the reversing power is on.

Battleships do not always run at full speed, and to secure as much steam economy as possible cruising turbines are therefore installed to increase the ratio of expansion, when steaming at cruising speed.

To obtain full power and speed, steam enters at M, and the main high-pressure ahead turbines at A, emerging at B, and entering the low-pressure ahead turbines at C, whence it is taken to the condensers, any intermediate speed being obtained by steam throttling until the cruising speed is required, when the connections are again altered, steam then enters the H.P. cruising turbine at E, exhausting at F. Thence the steam flows to the M.P. cruising turbine at G, on exhausting from which it divides into the two main H.P. turbines I, after which it passes to the low pressure ahead turbines C, and on to the condensers.

A variable speed can also be obtained, with the same connections, by tapping the main steam pipe and delivering live steam to the M.P. cruising turbine at N.

For reversing, high pressure steam is taken from M to the H.P. astern turbines J, exhausting out at K, and entering the low-pressure astern turbines at L, whence it passes direct to the condensers.

The length of steam pipe required in this case is enormous as compared with that necessary for an electrically driven boat of the same power.

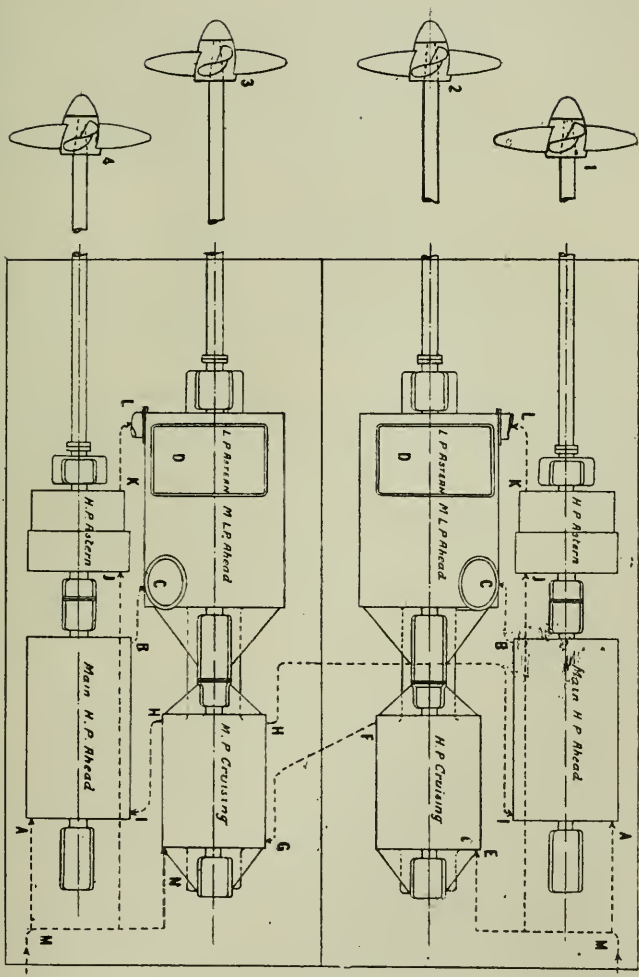


FIG. 6.

ENGINE ROOM PLAN—TURBINE DRIVE. DOTTED LINES SHOW MAIN PIPE CONNECTIONS.

FIG. 7.

Shows a layout of the Paragon system of ship propulsion providing for three set propeller speeds ahead or astern, the engine running always in one direction at a constant speed. The engine is coupled direct to the half-coupling A, and runs at say 400 r.p.m. at practically constant speed, turning the shaft in the direction shown by the arrow at B. On this shaft are mounted and driven a revolving field magnet C, a transformer-generator D, and slip-rings E and F. The stationary member G is a four pole synchronous polyphase alternating current generator. The member H is the stationary secondary and armature member of the transformer-generator (this machine adds to or deducts from the frequency as desired). The motor stator or primary member is shown at I, and the squirrel cage rotor J is coupled to the propeller shaft K.

The operating conditions are as follows—

FIRST SPEED AHEAD.—The connections are arranged with the transformer-generator running idle, and as only small power is required it is supplied by the synchronous generator direct to the motor, which is wound for 64 magnetic poles, the speed of the motor being say 25 r.p.m.

SECOND SPEED AHEAD.—The current is disconnected from the motor, and sent into the slip-rings F, so that the resulting magnetic flux revolves in the member D in the opposite direction to the mechanical drive. The members D & H are wound for 12 poles, so that the revolving magnetic polarity produced by the current from the generator armature G, revolves in the direction of the arrow O, and then the winding in the member H delivers a current with a frequency equal to a 8 pole machine driven at the engine speed of 400 r.p.m., or twice the frequency and voltage previously obtained from the synchronous generator. This current, being sent to the induction motor accelerates it to a speed of say 50 r.p.m., the actual power required being about one fourth of that for going ahead at full speed.

FULL SPEED AHEAD.—The current leading from the synchronous machine to the slip-rings F is now reversed in two of the three phases, so that the resulting magnetic flux in the member D makes a quarter turn per mechanical turn in the direction of the engine drive as shown at P, so that the current in H is generated with a frequency equal to a 16 pole machine driven at 400 r.p.m., equal to 53 periods per sec. at twice the voltage of the previous speed, the engine power being fully taken up. Reversing may be effected at any of the previous speeds, with two of the three leads between the generator and the motor reversed. This system is suitable when an internal combustion engine is the prime-mover, but with a higher speed machine such as a steam turbine, the method shown in Fig. 8 is best, where although the

principle is similar to the above, the transformer-generator has fewer poles than the synchronous generator.

In Fig. 7 the slip rings E, take the exciting current to the revolving magnet of the generator. M is the series field of the exciter; N is the contact which short-circuits the field winding of the series exciter, allowing the voltage to fall to zero when making changes in the connections of the mains, etc; V is the winding of the revolving magnet; U is the winding in the armature of the synchronous generator; Q is the primary winding on the revolving member D of the transformer-generator, and R is the secondary winding of the same; S is the primary winding on the stator of the motor, and T is the winding of the short-circuited squirrel cage rotor.

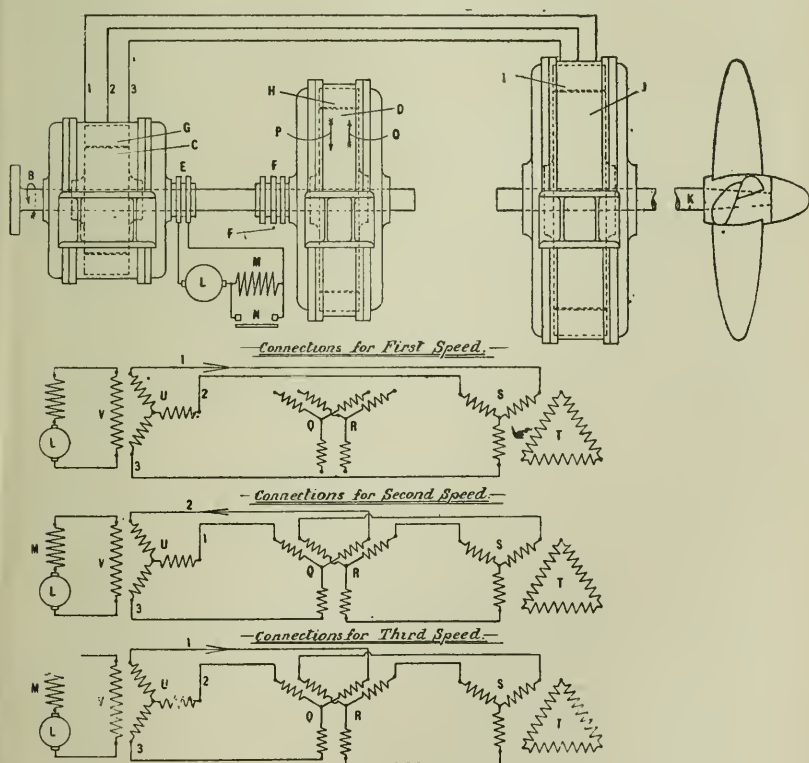


FIG. 7.

"PARAGON" SYSTEM ARRANGED FOR THREE SPEEDS AHEAD AND ASTERN.

FIG. 8.

This layout of the "Paragon" system consists of two small mechanically coupled machines, driven by a steam turbine. A is the turbine shaft, C the revolving magnet of the synchronous generator, D the primary member of the transformer-generator, E the iron forming the magnetic circuit of the synchronous generator, and F its winding. The slip-rings G take three-phase current from the synchronous generator to the primary of the transformer-generator, and H is the winding on the revolving member of the latter. I is the magnetic circuit of its secondary, J is its winding, K the slip-rings, and M the winding on the revolving exciting magnet.

DESCRIPTION OF WORKING.—With the turbine at 1,500 r.p.m. giving 1,000 h.p. on A, by exciting the slip-rings K three phase alternating current is generated on the windings F at 400 volts and 6,000 alternations per minute. With an induction motor of 60 magnetic poles driving the propeller shaft, by sending current of the above frequency and voltage into the stator winding of the motor, it would run at a synchronous speed of 100 r.p.m. or about two-thirds vessel speed. The control is similar to that in Fig. 7. Now disconnecting the leads from the generator winding F, and so connecting the current to the slip-rings G, the resulting magnetic flux in D revolves counter to the turbine drive. The 4-pole synchronous generator runs at 1,500 r.p.m., delivers current at 6,000 alternations per minute to the winding H, which has only two poles, so that the magnetic flux produced in D will revolve twice backward for each turn of the shaft B, and the windings J will have half the frequency and voltage of the synchronous generator, this current going to the stator of the motor, which will then run at 50 r.p.m. With the turbine at top speed, motor speed can be reduced by throttling the steam, etc., and so reducing the frequency.

FULL SPEED AHEAD.—If the leads between the windings of the synchronous generator and the slip-rings G be reversed in two of the three phases, the magnetic flux will revolve in D in the same direction and at twice the speed of the drive, and although it is only a two pole machine, driven at 1,500 r.p.m., the frequency and voltage will be 9,000 alternations per minute, and 600 volts. The motor will then run at the full (synchronous) speed of 150 r.p.m., and full work is given to the turbine, so that assuming the power transmission efficiency at 88% we get 880 shaft h.p. at 150 r.p.m. for 1,000 b.h.p. on the turbine at 1,500 r.p.m. Taking the steam consumption at 14lb. per k.w. hr. at the turbo-generating plant, with a motor efficiency of 93%, the steam consumption will be 11.9lb. per shaft h.p. hour, or 25% saving over the ordinary reciprocating steam engined boat of this power.

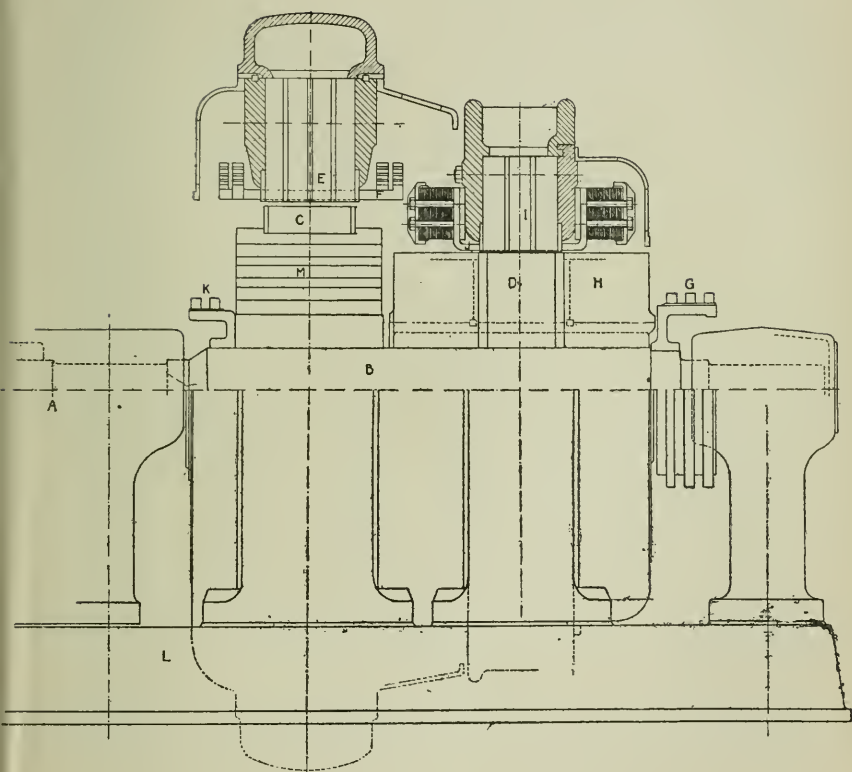


FIG. 8.

GENERATING UNIT FOR THREE FREQUENCIES AND MOTOR SPEEDS.

FIG. 9.

Shows the latest adaptation of the "Paragon" system for large powers, with the valuable feature that the power, frequency, and voltage, may be generated at constant speed on the prime-movers.

This layout is for 100,000 shaft h.p. at 172 r.p.m. on four shafts. The turbines in this case are similar to those at work at Essen in Germany, of the "Zoelly" type, made by Escher, Wyss & Co., of Zurich. Those at Essen give 28,000 h.p. at 1,000 r.p.m. with 27·5 inches of vacuum, and steam at 150lb. pressure, superheated to a total temperature of 572° Fahr. When running at sea with the high vacuum that can be obtained there, the steam consumption per b.h.p. hour of these turbines should not exceed 7·8lb.

It can be safely assumed that the electrical power transmission efficiency in this large power would be at least 93%, so that the total amount of steam used would be 8·4lb. per shaft h.p. hour, at full power and vessel speed. This would compare very favourably with the *Lusitania*, on which the 70,000 shaft h.p. at 190 r.p.m., is about 13lb. of steam per s.h.p. hr., using for main propulsion 910,000lb. of steam per hour. Such an electrically driven vessel would use only 840,000lb. of steam per hour for main propulsion, and would give 100,000 shaft h.p. at a propeller speed of 172 r.p.m. effecting a saving of 7·5% in steam and increasing the shaft h.p. by 43%.

The working of this system is as follows—

Steam enters at A, into the turbines 1, 2, 3, 4 and 5, marked B. Each of the turbines 1, 2, 4 and 5, is designed to deliver 20,000 b.h.p., and turbine 3 for 30,000 b.h.p. The 20,000 b.h.p. turbines run at 1,000 r.p.m., and No. 3 at 2,600 r.p.m., the latter being used only when the vessel is travelling at top speed. Turbines 2 and 4 each drive C, which is a 4 pole synchronous three phase generator, with exciting slip-rings D. These turbines also drive a 2 pole synchronous transformer-generator of which the rotating primary member is at E, slip-rings at F, direct current exciter armature at G, and magnetic fields at H. The stationary armature of the synchronous generator is shown at I, and the stator secondary member of the transformer-generator at J, these three machines being driven at a constant speed by the turbines at 1,000 r.p.m.

Turbines 1 and 5 each drive a 4 pole asynchronous transformer-generator at 1,000 r.p.m., the mechanically driven primary member being shown at C, and the slip-rings which take the electrical input at K. The stationary secondary member L is wound for three phase alternating current.

Turbine No. 3 drives two 4 pole asynchronous induction generators at 2,600 r.p.m. (but can equally well drive only

one). The stator armatures are shown at M and O, and the squirrel cage rotor members at N and P, the function of these machines being to boost up the electrical power on the mains so that the motors may give full power. The use of two machines as shown separates the electrical connections for the port and starboard sides of the power plant, and so avoids parallel operation of the electrical generating plant (but parallel operation on the "Paragon" system will not be difficult, because, the connections having been made under no-voltage conditions, the exciter is let on and the whole plant falls into step before the full power is on).

The squirrel cage induction motors are in sets of two, one to each of the four shafts, each motor having 58 poles and being designed for 12,500 b.h.p. at 172 r.p.m., the starboard side motors Q, turning the shafts when going in the direction S and the port side motors R, turning the shafts when going in the direction T.

The working is as follows—

FIRST SPEED AHEAD.—Either of the turbines 2 or 4 is started up and run at 1,000 r.p.m. and the controller gear may be operated from a distance by electric motors. The motors Q and R are in sets of four in parallel, all coupled together, and the connections are made so that when the exciter is put on to the slip-rings D, three phase current is delivered with a frequency of 4,000 alternations per minute from the stationary armature I. This current is led to the slip-rings F, and the resulting magnetic flux in the two pole primary member of this transformer-generator revolves in a counter-direction to the turbine drive, with the result that the stator secondary member 2 pole windings J are excited once for every revolution of the primary member E, so that a frequency equal to 2,000 alternations per minute is produced at half the voltage. This current is coupled to the motors, which then start with a powerful torque, and run at a synchronous speed of say 34 r.p.m., in the ahead direction.

SECOND SPEED AHEAD.—The exciting current is taken off the slip-rings D, and system falls to a no-voltage condition, when the connections are changed, so that the motors are coupled direct to the stationary armature I. The exciter is let on, and a frequency of 4,000 alternations per minute is sent direct to the stator windings of the motors, which then run up to a speed of 69 r.p.m. one turbine (No. 2 or 4) providing the necessary power.

THIRD SPEED AHEAD.—If No. 2 turbine be at work, the motors are now grouped in two sets, port and starboard, and turbine No. 4 is started and run at 1,000 r.p.m., the connections being made so that the 4,000 alternation current from the armatures I is taken into the primary windings of the transformer-generators through slip-rings F (as at the first speed) but in this

case two of the phases coming from I are reversed so that the magnetic flux revolves in the same direction as the turbine drive, with the result that the current comes out of the secondary member J at 6,000 alternations per minute and at a higher voltage, the motors then running at 104 r.p.m., the necessary power being easily met by two turbines, the other three being shut down.

FOURTH SPEED AHEAD.—The conditions are altered under no-voltage conditions, so that turbines 1 and 5 are started up and run at 1,000 r.p.m. and the 4,000 alternating current now going to the slip-rings K, polyphase alternating current is generated in the stationary windings of L, at a higher voltage and a frequency of 8,000 per minute, the 4,000 alternations from I being added to by the revolutions of the primary members C with turbines number 1 and 5. This 8,000 alternations per minute current is then coupled to the motors, which run at 138 r.p.m., the four turbines then producing the power required.

FULL SPEED AHEAD.—Turbine No. 3 is started up and run at its full speed of 2,600 r.p.m. (allowing $3\frac{1}{2}\%$ slip ahead on the induction generators). Both sides being alike, the working of the star-board side of the plant will be explained. Under no-voltage conditions 4,000 alternation current from I is sent to the primary member of the transformer-generator through slip-rings F, the current then coming from the secondary at 6,000 alternations per minute, and being delivered to the slip-rings K of the transformer-generator driven by turbine number 1. Current at a still higher voltage is then delivered by the secondary member L, at 10,000 alternations per minute (at this frequency the revolution speed of the motors would be 172 r.p.m., so that the 40,000 h.p. then coupled to the main conductors would not meet the demand for power at that vessel speed) the connections are made to the motors, and to the stator member of the induction generator M, the exciter is let on to the slip-rings at D, and the whole system rises in voltage, the motors accelerate to 172 r.p.m., and the total power is made up by turbine No. 3 which contributes about 15,000 h.p. by reason of the induction generator running slightly above the synchronous speed of the flux revolving in the member M, with the squirrel cage rotor inductor running at 2,600 r.p.m. The port side machinery is coupled in a similar manner, but the 10,000 alternation current is sent to the member O of the induction generator in the No. 3 turbine shaft, which then adds similar extra power to the electrical circuits of the port side motors.

REVERSING.—A very heavy reverse torque can be given to the motors by changing the connections, as at the first speed ahead, but with two of the three phases reversed between the transformer-generator secondary member J, and the motors, and so without the use of wasteful resistances the low frequency current will meet the need for sudden reversals.

CAL MARINE TRANSPORTATION.

JOURNAL OF THE SOCIETY OF ENGINEERS (INCORPORATED),

November, 1912.

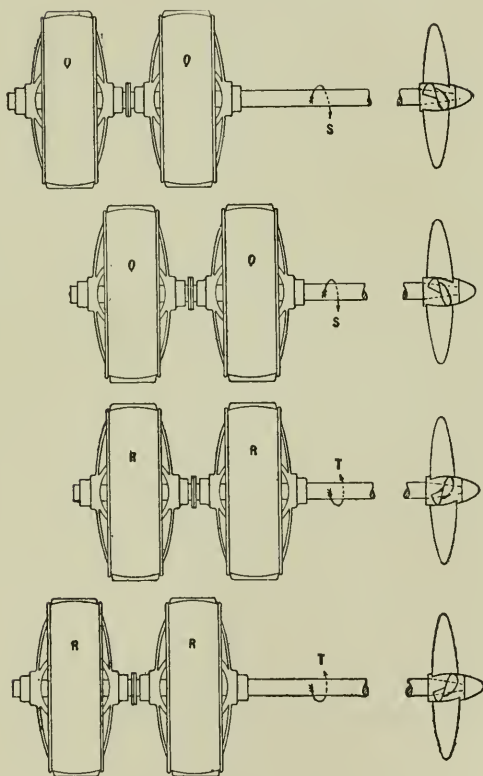


FIG. 9.

M FOR 100,000 SHAFT H.P., 172 R.P.M. (4 SHAFTS),
SPEEDS 1,000 AND 2,600 R.P.M.

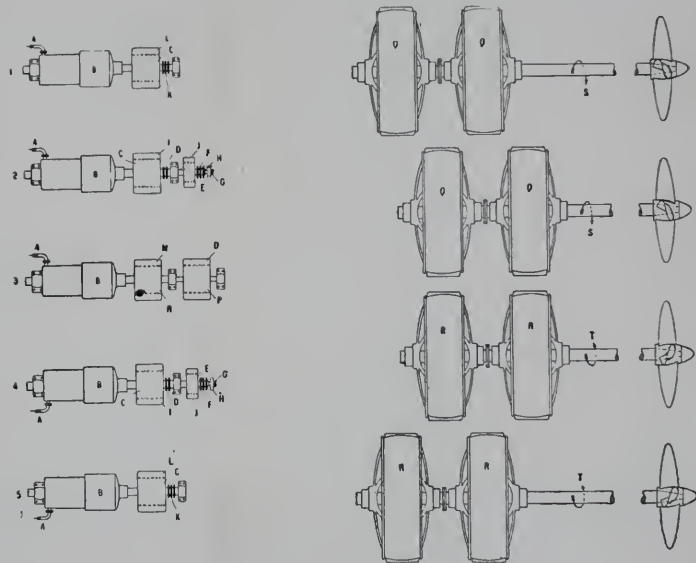


FIG. 9.

"PARAGON" SYSTEM FOR 100,000 SHAFT H.P., 172 R.P.M. (4 SHAFTS).

TURBINE SPEEDS 1,000 AND 2,600 R.P.M.

Any other speed can be given for travelling astern, by connections similar to those for going ahead ; but with two of the motor phases reversed as above, only three leads are required to the motors from the generating room, which is an advantage, as they are always connected to the motors, the necessary changes being carried out at the controllers. The advantages of the squirrel cage motor for this heavy power work need no further comment, the intermediate speeds being given by slightly changing the revolutions of either of the turbines 2 or 4, and many other adjustments are possible.

DISCUSSION.

On the motion of the **President** a vote of thanks was accorded to the author for his paper.

Mr. F. T. Chapman said that he would offer only a few remarks on the electrical aspect of the question. The great advantages which the author had pointed out as belonging to the squirrel cage motor, namely, its simplicity, its robustness, and its high efficiency, made it practically an ideal machine for driving a propeller. In discussions on the subject of the electrification of the main drive of ships the question of alternating versus continuous current had been very much debated ; but it was generally supposed that the continuous current machine was not suitable for the very large powers which would have to be employed, and, consequently, opinion seemed to favour considerably the adoption of alternating current. As the squirrel cage motor was such a simple and efficient machine, it naturally received the greatest favour. Under the conditions obtaining on board ship the successful driving of the squirrel cage motor required that the frequency of the supply should be variable. The author had satisfied the requirement in his "Paragon" system.

The supply of power to a motor at a variable frequency might be effected in one of two ways, either by supplying a few fixed frequencies, say two or three, or by supplying a continuously variable frequency. If they could supply in a satisfactory manner a continuously variable frequency, they would have all the advantages of the well known Ward-Leonard system of continuous current supply, together with the advantages of the simple squirrel cage motor. Two Austrian engineers had recently carried out some experiments with a system of continuously variable frequency.* They arranged on the

* *Elektrotechnik and Maschinenbau*. Vol. 30. pp. 637-643. August 4th, 1912.

main shaft (that driven by the prime mover), two generators, one an alternating-current generator and the other a smaller continuous current machine. The latter supplied power to a rotary converter which could be run at variable speed, and would supply the larger generator with power at variable frequency. The second generator acted not only as a generator but also as a frequency changer, with the result that the frequency obtained from the main generator could be varied over very wide limits. The rotary converter, however, was additional plant, it was not really active in supplying power to the motor which drove the propeller when it was in action. The larger the variation in the frequency and, consequently, the larger the provision for varying the speed of the propeller, the greater was the amount of the additional plant, compared with the plant which was actively engaged in propelling the vessel at full speed. It was therefore of considerable importance to determine what was the minimum range of speed which would be suitable for driving a ship. The most difficult condition under which the motor had to work occurred when reversing with the vessel running at full speed ahead, when it would be necessary for the motor to be capable of developing full load torque when reversed in order to retard the propeller and hold it stationary while the ship was running forward. If this was to be possible without the motor taking more than $1\frac{1}{2}$ times to twice full load current (and the current would be limited to that because of the heating which a large current would cause in the windings of the motor, and also because a very heavy current would reduce the voltage of supply and this in its turn would reduce the available torque given by the motor), it would be necessary to supply to the motor a frequency of one-tenth the normal running frequency unless they adopted a specially high resistance rotor winding. This was rather a heavy condition, and it would involve, on the system of which he was speaking, a total plant capacity equal to twice the capacity of the motor, approximately. It would appear, therefore, that there was considerable scope for improvement in the methods of generating variable frequency currents.

He thought that the author was to be congratulated on the persistence with which he attacked the problem, and he hoped that his efforts would soon be crowned with some tangible success.

Mr. Horace Boot said that the paper was instructive and original, and it was a pleasure to have the opportunity of discussing the latest development of the subject. The author had brought forward in a forcible manner the fact that, to obtain high efficiency, the propeller shafts must revolve slowly, while the turbines must revolve at nearly the velocity of steam, and it was clear that the idea of driving ships economically by

turbines was wrong. There must be some connecting link between the high speed turbine and the low speed propeller. One was surprised to notice that the Channel boats on coming into port usually had to turn round and back in. One would naturally wonder why they did so, as in a heavy sea the loss of time involved in such an operation was important. It was of little use to cross 21 miles of sea in rapid time, only to lose time by having to reverse and back when going into port. It was not generally known that that state of things was due to the fact that a ship direct driven by turbines could not safely come straight into harbour for want of sufficient way for steering purposes, and because direct-driven turbine ships had to use very small propellers at high speed. In other words, the propeller blade was too small to control the ship absolutely, whereas, with a reciprocating engine, the propeller blade being much larger, gave very much better control. When coming out of Dover or some other harbour where the tide was very strong, one saw how necessary it was for the ship to have a good way on her before she could get out.

There were one or two points which the author had not touched upon. One was, what would be the cost of equipping an ordinary tramp steamer by the author's system as compared with the cost of ordinary reciprocating engines? This was very important to designers, because a reciprocating engine at sea worked very economically and enabled perfect control to be kept over a ship in heavy seas.

Another point was, what would happen to a ship should the induction motor break down? It was easy to repair a reciprocating engine, but with electrical motors, including induction motors, it was not always easy, first, to locate the cause of the trouble, and secondly to put it right quickly.

A third point was that it was extremely important in ship propulsion for the engineer to have warning of anything going wrong. Unfortunately electrical machinery did not always give as much warning as one would expect to get with a reciprocating engine.

Mr. A. H. Binyon said that he had studied different means of transmitting power from the prime source, to the wheels of motor cars, and to screw propellers. His difficulty had been to get a good variable gear, as he wanted a very small high speed generator and great power at the screw propeller of the ship, and at the tyre of the motor car. He at length found that the author's system, with variable voltage and frequency gave just what was wanted, namely, maximum power in the smallest possible space.

REPLY.

Mr. W. P. Durtnall said that Mr. Chapman had not told the meeting that for some years past he had been designing the "Paragon" system in its various applications, especially for driving the auxiliary machinery, and his knowledge of the design and construction of polyphase alternating currents machinery had been of great service to him (the author). As Mr. Chapman had said, in practical electrical propulsion, they must have simplicity, and although in 1905 he held patents for the electrical propulsion of ships on the continuous current principle, he had allowed them to lapse on account of their complications. The only machine that would meet the case was, in his opinion, the squirrel cage motor. Mr. Chapman had mentioned the troubles that arose in getting the machine, ideal as it was in many ways, to meet the conditions of sea-going engineering, in regard to the starting and reversing torque, and the running efficiency at various speeds. The one way out of the difficulty was to use current of variable frequency and voltage. The use of slip-rings was certainly wasteful, and until 1908, there was no means of starting big machines. He had read of the interesting investigations of the squirrel cage machine made by two Austrian engineers, who had said that if they could get variable frequency and voltage, this method of marine propulsion was an ideal one. It was on those lines that he undertook the great expense and trouble involved in gaining the information necessary to prepare a sound engineering proposition which he could lay before practical sea-going engineers.

The full load and variable torque conditions were quite different in traction work. In marine work the full torque was required at full speed, in other words full power was required; whereas in traction work it was just the opposite. In road traction the torque at starting exceeded that at full speed.

He had had a similar experience to that of Mr. Horace Boot, when crossing from Ostend with a fairly heavy wind and tide. On arrival at Dover, to his surprise the boat stopped, turned and then went astern into the harbour. On making enquiries of the engineer, whom he knew personally, he was told that it was impossible to enter the harbour at full speed not having full reverse power. To go in dead slow with the tide and the wind outside and the dead water inside, would result in the tide taking charge of the stern of the boat, so that steering way could not be kept. In other words, the small turbine propeller did not have the same holding effect on the water, against the tide and wind, as the old-fashioned slow speed screws, driven by reciprocating engines.

With regard to cost, if a thing was not commercially good, it was no good. Unfortunately, owing to the very small demand for machinery such as would be required ultimately, there were few firms who would design machinery and quote to specifications. No doubt, when once the demand was set up, the cost would be lower than that of the present direct coupled steam methods. At present, patterns and so on made the first stages very costly. In the case of the *Jupiter*, he believed that the machinery when finished and installed would be much cheaper than reciprocating engines.

A point which had made him work on the squirrel cage machinery with such enthusiasm, was that at sea, where the lives of all depended on the engineering plant, they must have the simplest and most reliable machinery obtainable. If they had a generating plant of five thousand horse power in a power station, and they attempted to "monkey" with a 50 h.p. motor, the machine would be quickly burnt up if it were not properly looked after. But suppose that they had a 1,000 h.p. motor, supplied by a 1,000 h.p. generator, that made a considerable difference. With his motor omnibuses, which had a 40 h.p. engine, he had tried to burn up the motor, but he had not done so yet, although he had stood them for hours on a hill, running with full load in short-circuit conditions; those conditions would never occur at sea.

The greatest trouble in this matter was the disposal of the power transmission efficiency losses in the machine rooms. On the *Jupiter* they let the air go by atmospheric pressure into the motor and the generator, drew it out, put it into the fire rooms and used it over again. They were able to recover some of the heat lost, by warming the air which went into the furnaces. Although it was not a great deal, it was the right thing to do on board a ship, and he appreciated the way in which the American people had tackled the question of ventilation.

As regarded warning about things going wrong, if they were likely to go wrong there was not much use for them at sea, but even there things occasionally went wrong without warning, even turbine machinery and reciprocating engines. Those who knew, would be able to say how very well and accurately the electric motor could be controlled. There was no accurate method of determining the exact brake horse power taken by a propeller. Although the torsion meter showed the horsepower fairly accurately, there was no accurate means for finding the horsepower on the reciprocating engine shaft.

He believed that, when they got electrical motor driven shafts running, the naval architect and the designer of propellers would know much more than they now knew about the conditions under which screw propellers worked, because by

electric meters they would be able to tell accurately what was the power on the shaft.

The investigation of the balance of the thrust of the propeller shaft by an electric motor was of interest. Attempts had been made to get this balance by hydraulic pressure. He believed that he would soon find a means of balancing the propeller thrust, and they would then know the thrust produced and the thermal efficiency of vessels thus driven.

When the "Paragon" system of ship propulsion was first introduced, it was looked upon as a mad idea by those who had not the inclination to study the principles involved. Now people were beginning to learn, and practically all of his time, during the last six years had been devoted to educating practical engineers in his methods. He had no fear as to the ultimate adoption of his system, when once those engineers agreed with his principles. As recently as 1908, when the principle was exhibited at the Franco-British Exhibition, insulting remarks appeared in the engineering press. The very people who were then for pulling the system to pieces were now endeavouring to get patents on the same lines. He had been kept busy opposing grants of patents, and had been most successful in his opposition.

The whole matter was an engineering one, and it warranted investigation by marine and electrical engineers, naval architects and ship builders. It was a new method of raising the thermal efficiency of ships, taking advantage of the latest ideas in prime movers and heavy power electrical engineering.

One of his greatest ambitions was to make marine machinery reliable and the way to get reliability was to use the squirrel cage induction motor.

December 2nd, 1912.

JOHN KENNEDY, PRESIDENT.

IN THE CHAIR.

TEST DEFLECTIONS IN REINFORCED CONCRETE.

By PERCY J. WALDRAM, F.S.I., M.C.I.

[The following is the notation used in this paper :—

A_t = Area of tensile reinforcement (square inches).

A_c = Area of compressive reinforcement (square inches).

a = Arm of the resisting moment or lever arm (inches).

a_r = Arm ratio $= \frac{a}{d} \therefore a, d = a$.

b = Breadth of flange of beam (inches).

c = Compressive stress on the compressed edge of the concrete (pounds per square inch).

d = Effective depth of beam (inches).

d_c = Depth or distance of the centre of compression from the compressed edge (inches).

d_s = Total depth of slab (inches).

E_c = Elastic modulus of concrete (pounds per square inch).

E_s = Elastic modulus of steel (pounds per square inch).

f = Extreme fibre stress (pounds per square inch).

m = Modular ratio E_s/E_c .

n = Depth of neutral axis from the extreme compressed edge (inches).

n_r = n/d = the neutral axis ratio $\therefore n, d = n$.

R_c = Compressive resistance moment = Resistance moment of the beam in terms of the compressive stress (pound-inches).

R_t = Tensile resistance moment or resistance moment in terms of the tensile stress (pound-inches).

$r_c = \frac{A_c}{A_t}$ = ratio of compressive to tensile reinforcement.

$r = \frac{A_t}{bd}$ = ratio of area of tensile reinforcement to the area bd .

S_m = Section modulus.

$s_r = d_s/d$ = the slab depth ratio, *i.e.* the ratio of the slab depth to the effective depth of the rib of a T beam.]

In complying with the invitation of your Council to write at short notice a paper on reinforced concrete, the author has selected the above subject as being one which, not only calls for the closer attention of engineers, but which needs that closer

attention without delay, before the proposed L.C.C. Regulations fix a standard of deflection which may or may not be correct, or even safe.

The relation of stiffness to strength.—There is no need for the author to remind members of this Society that the stiffness of a beam is no criterion of its strength, unless due regard be paid to the factors of depth and fibre stiffness ; but it is not too easy always to appreciate that the fibres of a short deep girder, deflecting under load to say half an inch, are possibly being punished much more severely than those of a long shallow girder deflecting say three inches. Still more difficult is it to avoid the drawing of incorrect assumptions from the very minute deflections of reinforced concrete beams, because in their case not only are the formulæ for strength very tedious, but the writers of text books have failed to establish any connection between them and deflection, and seldom even to show how deflection can be calculated at all.

Small deflections in Reinforced Concrete not a proof of strength.—When beams of reinforced concrete are tested to say $1\frac{1}{2}$ times their working load, extremely small deflections are recorded, which are triumphantly quoted as evidence of the enormous strength of the new material, because a steel beam of the same proportions would have deflected very much more under its ordinary working load.

A point which is seldom mentioned, however, is that the deflections are small because the greatest working loads and stresses which we dare to place on reinforced concrete are so very much less than those which we habitually work to in wood or steel.

Reinforced Concrete weaker than Steel or Fir.—A deflection of say $\frac{1}{2}$ in. in an ordinary wood or steel floor beam under a test load might indicate quite a satisfactory factor of safety. The same deflection in a reinforced concrete beam of the same proportions would mean that the structure was on the verge of total collapse.

Reinforced concrete has so many advantages over wood and steel in its great durability, its adaptability, and its simple and monolithic character that there should be no need for its exponents to claim for it the strength of steel or even that of ordinary fir. It is a much weaker material than either, and to pretend or believe otherwise is to court disaster. The safe load on a fir beam can always be trusted to destroy a reinforced concrete beam of the same size unless the latter is heavily reinforced in compression.

It does not require much detailed investigation to appreciate that the fibre stress of 600 lb. per square inch, which is the limit of good concrete in compression in beams, obviously cannot

produce deformations comparable with those which result from 11 or 12 cwts. per square inch on timber (quite a light loading) or $7\frac{1}{2}$ tons per square inch on steel.

Of course concrete beams can be reinforced in compression, but the strength of the concrete surrounding the compressive reinforcement is still the governing factor, and double reinforcement is very uneconomical.

Reinforced concrete has the advantage of being easily formed with fixed ends, encastré edges, and into ribbed floors in which the transverse slabs assist the main beams, and the strength of each part contributes to that of one strong monolithic whole; but even with those advantages the proportions of the parts have to be more generous than would be necessary with wood or steel and the deflections under test loadings are necessarily far less than we have been accustomed to in those materials.

Deflections of Beams under a given stress.—It should be carefully remembered that we can obtain the deflection of a beam of a given depth, span, and material under a given system of loading, without troubling about its moment of inertia or its section modulus, or even the amount of the load, provided that we know that the loading is stressing the fibres to a given amount.

The formula expressing this is :—

Deflection = $\Delta = \frac{k/l^2}{Ed}$; k being a constant varying with the type of beam and the method of loading. For girders of uniform section under distributed load k is $\frac{5}{32}$. The term d is either the depth (in symmetrical sections) or (in unsymmetrical sections) twice the distance between the neutral axis and the layer of fibres stressed to the amount f . E is the elastic modulus of the material.

Conversely, in all beams having the same proportion of depth to span, any given proportion of deflection to span under the same system of loading must indicate the same fibre stress in material of the same stiffness, whatever may be the size of the beam, the span or the load.

Reinforced concrete therefore must always be expected to shew deflections far less than those to which we are accustomed. Long before it deflects to anything like the extent that wood or steel does it would be time for those conducting the test to look to their own safety.

The L.C.C. Draft Regulations.—The draft regulations of the London County Council specify certain degrees of deflection which would appear to need careful consideration, and it is hoped that the discussion this evening may elicit opinions as to whether they should be altered; and if so to what extent and upon what lines. It is necessary not to lose sight of the fact

that these regulations require the approval of the Local Government Board before they can come into force; and that until they are so approved it is the obvious duty of professional men to endeavour by all available means to bring them to a high state of efficiency. Their scope may be nominally limited to special buildings in London alone, but when once adopted they will most certainly be regarded as a standard, and their conditions will be specified in cases where they have no legal status whatever.

The Act of 1909 which authorises their compilation requires the Council, before applying for their approval by the Local Government Board, to give notice to the Surveyors' Institution, the Institution of Civil Engineers, the Royal Institute of British Architects, and the Concrete Institute. Every member of any of these Institutes can therefore approach his Council or the Local Government Board direct, if it should appear to him to be desirable that any of the 160 clauses should be altered.

The Regulations in their present form appear to have been carefully compiled from codes already in existence in Europe and America where reinforced concrete is far more extensively used than in England. At least one of these codes—that of the French Government—was based upon several years of valuable and exhaustive experimental research. It would therefore scarcely be expected that any serious errors of principle would have been generally adopted, and clauses upon which the foreign codes are unanimous, or are in general agreement, ought apparently to be good enough to adopt.

But precisely the same considerations obtained when other codes were drawn up. The natural desire of the codifying authority to be able to shew precedents for its Regulations is only too favourable to the perpetuation of errors, which acquire fresh status every time they appear. It would therefore certainly seem to be desirable that the Institutions should do all they can to awaken interest in these Regulations and secure the greatest possible volume of criticism from their members; so that even if errors of principle may have crept into other codes, they shall not be repeated in the first British Code.

Early in the present year the author was consulted with reference to a case where the parties had agreed that the Regulations as printed in the Council's Minutes should be worked to. This opportunity of applying them to the problems of a somewhat complicated design necessitated a close examination of their provisions, and the result was, to say the least, disquieting.

For instance the clauses determining the strength of columns—based like the French Code and the R.I.B.A. Report, on a mistaken application of Euler's formula*—were unworkable; whilst those relating to deflection would appear to be positively dangerous.

* See *Engineering*, April 5th, 1912.

Clause 23 allowed beams of a lesser depth than $\frac{1}{24}$ span provided the calculated deflection was less than $\frac{1}{600}$ span,—regardless of the fact that even with absolutely free ends the concrete of a beam $\frac{1}{24}$ of the span in depth deflecting $\frac{1}{600} l$ would be stressed to nearly 700lb. per square inch. Thus :—

$$\Delta = \frac{k/l^2}{Ed}, \text{ and when } \Delta = \frac{l}{600} \text{ and } d = \frac{l}{24} \text{ then}$$

$$f = \frac{24 \times E}{5 \times 600 \times 24} = 666 \text{ lb. per sq. in.}$$

$$(E = 2,000,000 \text{ lb. per sq. in.})$$

whilst in beams with fixed ends it meant anything up to 3,330lb. per square inch. As the clause did not specify whether test or working load was to be calculated for it might have been merely harmlessly unworkable, especially as there was no method specified for calculating the deflection of T and double reinforced beams.

But Clause 143 specified the test by means of which the District Surveyor should determine whether or not suspected work should be condemned as being a deflection of $\frac{1}{600}$ of the span under the full working load. A short deep beam with fixed ends or a thick square slab with four fixed edges was thus to shew precisely the same degree of flexibility as a long shallow beam with absolutely free ends.

Of course this was no test at all. No beam or floor of ordinary proportions could ever shew such a degree of deflection, it would simply cease to exist. A beam of only $\frac{1}{15}$ of its span in depth, even with absolutely free ends, whatever its section, is necessarily being deformed when the deflection reaches $\frac{1}{600}$ of the span, to an extent which can only be consistent with a stress of 1,066lb. per square inch on the concrete.*

No amount of compressive reinforcement can make any difference, because when that degree of deflection is reached the concrete surrounding the compression rods is receiving a stress under which it is liable to spall off and leave the rods denuded and free to buckle. If the beam were deeper or if the ends were fixed, as they are in the great majority of cases, the specified degree of deflection would be still more impossible.

But no beam, however bad or shaky, could be condemned under the clause so long as it shewed under test load any less deflection. Clauses 143 and 144 not only gave an implied official approval of a test deflection which would be highly dangerous to everybody concerned, but it would have defeated its own object

* The depth in the foregoing Clauses should be $2n$; but allowance must be made for the concrete in tension, which although neglected lowers the neutral axis. Hence $2n$ is more than the full depth.

by preventing the condemnation of any beam or floor which could just stand about $1\frac{1}{4}$ times its calculated load.

These and other points were submitted to the Council of the Surveyors' Institution, who promptly met and considered them and made representations which at the time of writing are presumably still under consideration.

Suggested standard of deflection under test load.—The author's suggestion made with regard to deflection was that the standard should be $\frac{1}{1000} l$ on a beam $\frac{1}{20}$ of the span in depth under the calculated load, with free ends and distributed loading; the effect of any conditions other than these being duly allowed for in each case. This would apparently have been equivalent to about 480 lb. per square inch on the concrete. Of course any test which increases only the superimposed load varies in severity, being lenient on heavy beams and severe on light ones; a 25% increase on the total calculated load may or not be equivalent to a 50% increase on the superimposed load, but it is estimated to do so in the average case.

Effect of ordinary end fixing not yet fully determined.—It would obviously be better to have a standard criterion of deflection applicable direct to the fixed ends customary in reinforced concrete beams. But whereas, as will be seen later, we can predetermine the deflection of reinforced concrete beams with free ends and compare it with actual tests, experimental data are lacking as to the actual effect of the ordinary methods of fixing the ends of such beams; which are, it must be remembered, almost invariably doubly reinforced at the ends to meet the reverse bending moments over the supports, and are therefore of unequal stiffness. The theoretical effect of complete end fixing in a beam of uniform section is to reduce the deflection to $\frac{1}{5}$; but to stipulate for a deflection of $\frac{1}{5000} l$ with fixed ends might be right or it might be wrong. We do not know.

Experiments to determine the point would not be very expensive or difficult, and there is power under the parent Act for the Council to make them. But until the point is determined, at least approximately, it is obviously impossible to legislate on a basis about which we know practically nothing.

Importance of a correct standard.—If the standard of stiffness be fixed too high good work will be unjustly condemned; if it is too low, bad and dangerous work will receive an undeserved certificate of strength. The minute range of the deflections makes it all the more necessary to fix the standard with the greatest care.

The calculation of deflection under given loading where the stress involved is unknown.—The thankless field of active legislation can now be left for the less exciting but far more interesting study of engineering problems.

The fact that reinforced concrete has been smothered with a mass of intricate formulæ scarcely makes it inviting to the general practitioner. If we had to calculate the moment of inertia every time we used a rolled section we should leave mild steel to experts and go on building in masonry, cast-iron, and wood. Because the formulæ for reinforced concrete continually reiterate properties which might just as well be obtained from tables or diagrams, we leave the subject to experts, and stick to mild steel and the Tables of Properties of British Standard sections. The British engineer requires to be personally assured of the accuracy of his calculations,—and when the R.I.B.A. Report tells him that the moment of resistance of a T beam is :—

$$cbdd_s \cdot \frac{s_r^3 + 4 mrs_r^2 - 12 mrs_r + 12 mr}{6 (s_r^2 + 2 mr)}$$

he prefers to use a rolled joist.

As a matter of fact about half the terms in that formula are unnecessary and the other half can be tabulated and plotted on diagrams; so that the designer picks out a T section from his diagrams just as easily as he can pick out a rolled joist. The formulæ used herein are necessarily set out in full, but for use in the office their values are obtained from plotted diagrams.

Only when the subject of reinforced concrete is thus dug out of the overlying strata of mathematical symbols is it possible for the average engineer with limited time and less leisure to investigate its principles. Let us endeavour to excavate the subject of deflection.

The actual and exact measurement of the strains produced by carefully measured stresses is an operation full of interest and instruction to the engineer and when the theoretical and actual deflections are plotted side by side their comparison is especially useful.

In beams of wood and steel it is a comparatively simple matter to predetermine and plot the deflection due to any given loading; but in reinforced concrete beams the unnecessary complexity of the standard calculations for strength has apparently scared investigators from attempting to deduce the moment of inertia of a section. As a matter of fact when calculating the strength, all the necessary calculations to determine the moment of inertia are made, and when this is obtained the ordinary formula $\Delta = \frac{k' W l^3}{EI}$ can be applied with the same facility with which it is used to ascertain the deflections of wood and steel beams.

In this standard formula, k' is a constant varying with the type of beam and the method of loading, W is the total load

in lb., l is the span in inches, E is the modulus of elasticity of the material in lb. per square inch, and I is the moment of inertia of the section in inch units.

Deduction of moment of inertia from moment of resistance.—

The difficulty of applying this standard formula to reinforced concrete beams has been that the formulæ for moment of resistance do not use the moment of inertia. But the moment of inertia is simply the section modulus multiplied by the distance y of the neutral axis from the layer of fibres with regard to which the section modulus has been calculated.

$$\text{or } S_m = \frac{I}{y}, \quad I = S_m y$$

The section modulus for the outside skin of concrete is expressed by the formula which determines the moment of resistance of the section with regard to the concrete, with the term c denoting the stress on the concrete omitted. Similarly the section modulus for the tensile reinforcement is merely the formula which determines the moment of resistance of the section with regard to the steel, with the term t denoting the tensile stress omitted.

We can therefore obtain the moment of inertia either from the R_c or the R_t formula by omitting c or t and multiplying by the distance of the neutral axis from the fibres under consideration. This will be the well known dimension n in the one case and $d - n$ in the other.

Moment of inertia of rectangular beams, single reinforcement.—

The standard formula for the moment of resistance due to the strength of the concrete is

$$R_c = \frac{cbd^2}{2} n_r \left(1 - \frac{n_r}{3}\right) \text{ or } \frac{cbn}{2} \times a$$

The corresponding section modulus would therefore be $S_{mc} = \frac{bna}{2}$ and the moment of inertia

$$I = \frac{bna}{2} \times n \text{ or } \frac{bd^3 n_r^2}{2} \left(1 - \frac{n_r}{3}\right)$$

The moment of resistance due to the strength of the steel is

$$R_t = trbd^2 \left(1 - \frac{n_r}{3}\right) \text{ or } t A_t a \text{ and the section modulus } S_{mt} = A_t a$$

In deducing the moment of inertia from this it must be remembered that the formula is based on the assumption that a compound section of steel and concrete acts in the same way as an equivalent section of concrete composed of the original section of concrete plus the area of steel replaced by an area of concrete equal to $A_t \times m$ or $15A_t$.

The moment of inertia will therefore be

$$15 rbd^3 \left(\frac{1-n_i}{3} \right) (1-n_i) \text{ or } 15 A_t a (d-n)$$

When using the formula $\Delta = \frac{k'Wl^3}{EI}$ with either of these values (which should be equal to each other if the calculations are correct) the modulus of elasticity used must be that of concrete or $E=2,000,000$ lb. per sq. inch.

Moment of inertia of T sections, single reinforcement.—The value of R_e being:—

$$cbd^2 s_i \left(1 - \frac{s_i}{2n_i} \right) \left(1 - \frac{3n_i s_i - 2s_i^2}{6n_i - 3s_i} \right)$$

and R_t being $trbd^2 a_i$ or $tA_t a$.

The corresponding section moduli would be

$$S_{mc} = bd^2 s_i \left(1 - \frac{s_i}{2n_i} \right) a_i$$

and $S_{mt} = A_t a$.

The value of I would therefore be

$$I = bd^3 s_i \left(1 - \frac{s_i}{2n_i} \right) a_i \times n_i \text{ or } 15 rbd^3 \left(1 - \frac{n_i}{3} \right) (1-n_i)$$

or $15 A_t a (d-n)$ as before.

Moment of inertia of rectangular beams, double reinforcement.—The value of R_e for any given position (dc_i) of the compressive reinforcement being—

$$R_e = cbd^2 \left(\frac{n_i}{2} + mrr_c \cdot \frac{n_i dc_i}{n_i} \right) a_i$$

and $R_t = tA_t a$

The corresponding section moduli would be

$$S_{mc} = bd^2 \left(\frac{n_i}{2} + mrr_c \cdot \frac{n_i - dc_i}{n_i} \right) a_i$$

and $S_{mt} = A_t a$

The moment of inertia would be

$$I = bd^3 \left(\frac{n_i}{2} + mrr_c \cdot \frac{n_i - dc_i}{n_i} \right) a_i n_i$$

or $15 A_t a (d-n)$ as before.

The lever arm of doubly reinforced beams is obtained from formulæ, or better still plotted formulæ, in the usual way.

Moment of inertia of T sections, double reinforcement.

$$R_e = cbd^2 \left\{ s_i \left(1 - \frac{s_i}{2n_i} \right) + mrr_c \left(1 - \frac{dc_i}{n_i} \right) \right\} a_i$$

and $R_t = tA_t a$

S_{mc} is therefore

$$bd^2 \left\{ s_r \left(1 - \frac{s_r}{2n_r} \right) + mrr_c \left(1 - \frac{dc_r}{n_r} \right) \right\} a,$$

and $S_{mt} = A_t a$ as before.

The moment of inertia is

$$I = bd^3 \left\{ s_r \left(1 - \frac{s_r}{2n_r} \right) + mrr_c \left(1 - \frac{dc_r}{n_r} \right) \right\} a n_r$$

or $A_t a (d - n)$ as before.

Comparison of calculated with actual deflection.—Figs. 1 to 8 shew the application of the foregoing methods to well known tests. Particulars of the extensive series of tests at University of Illinois conducted by Prof. Talbot in 1904 and 1905 will be found in Messrs. Marsh and Dunn's well known book.

Particulars of Messrs. Kirkaldy's tests were published in several technical papers in 1911. *Concrete and Constructional Engineering* for May, 1906, has a description of the French Government tests.

When the recorded deflections of similar beams provided with different shear reinforcement are plotted against the theoretical "straight line" result, it is possible to note very instructive characteristics in the varying difference between the curve and the straight line. The author is at present conducting a small series of such tests at the Westminster Technical Institute. The testing apparatus has all been devised and made by the school staff, and its delicacy is remarkable, but its range is far too limited to enable definite conclusions to be drawn from the results. The author ventures to draw particular attention to the beam which is the subject of Fig. 8. It is doubly reinforced and the compressive reinforcement is not at the centroid of the concrete in compression, conditions which are generally supposed to make the calculations almost too intricate to be possible. By using the foregoing methods, almost identical values were obtained for the moment of inertia when calculated from either side of the beam, and the plotted deflection cuts the actual curve in exactly the usual way.

The author trusts that in necessarily drawing attention to the want of intrinsic strength of individual members of reinforced concrete structures he will not be considered to be disparaging a material which for many purposes is the finest we have. No material can attain its full growth in an atmosphere of foggy mystery. Until engineers as a body can appreciate its principles and know its weak points as well as its advantages it will not be used with the confidence which it deserves.

NOTE.—In the following diagrams the dotted line shows the theoretical deflection implied by the standard straight line formula; the full line shews the actual deflection.

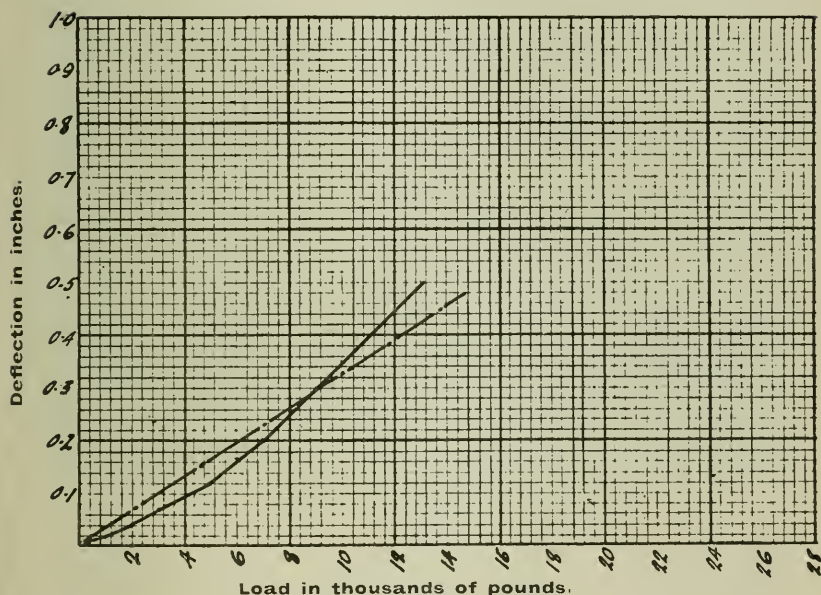


FIG. 1.

Beam No. 47 Talbot 1905 Experiments. Rectangular beam single reinforcement. Load distributed. No shear reinforcement. Ends free.

$$l = 144\text{in.} \quad d = 10\text{in.} \quad b = 8\text{in.}$$

$$A_t = \text{Four } \frac{1}{2}\text{in. round bars} = 0.785 \text{ sq. in.}$$

$$r = \frac{0.785}{80} = 0.98\% \quad n_r = 0.4175 \quad a_r = 0.8614$$

$$n = 4.157\text{ins.} \quad d - n = 5.843\text{ins.}$$

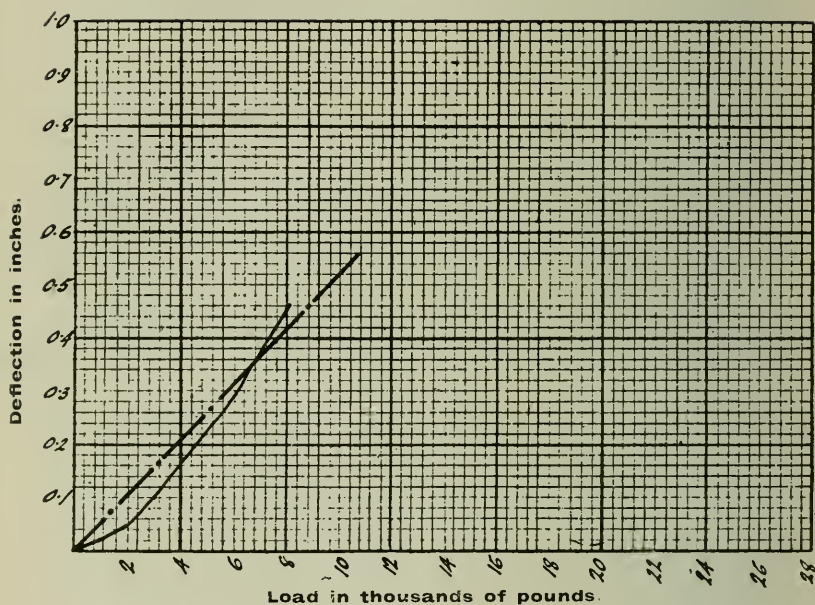


FIG. 2.

Beam No. 30. Talbot 1905 Experiments. Rectangular beam single reinforcement. Load central. No shear reinforcement. Ends free—

$$l = 144 \text{ in.} \quad d = 10 \text{ in.} \quad b = 8 \text{ in.}$$

$$A_t = \text{Four } \frac{1}{2} \text{ in. round bars} = 0.785 \text{ sq. in.}$$

$$r = \frac{0.785}{80} = 0.98\% \quad n_r = 0.4175. \quad a_r = 0.8614.$$

$$n = 4.157 \text{ ins.} \quad d - n = 5.843 \text{ ins.}$$

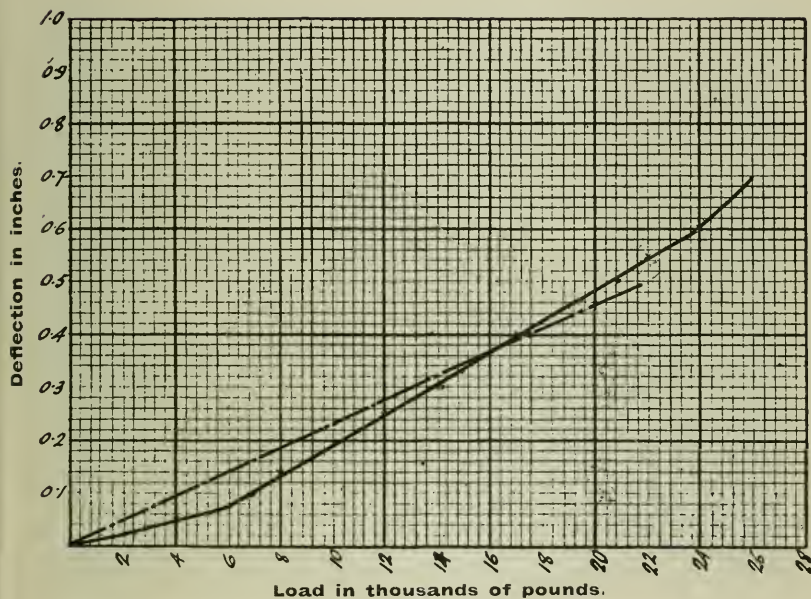


FIG. 3.

Beam No. 27. Talbot 1904 Experiments. Rectangular beam single reinforcement. Load at $\frac{1}{3}$ points.

$l = 168\text{in.}$ $d = 12\text{in.}$ $b = 12\text{in.}$

$A_t = \text{Four } \frac{3}{4}\text{in. square bars 2 bent up} = 1.692 \text{ square in.}$

$$r = \frac{1.692}{144} = 1.175\% \quad n_r = 0.43 \quad a_r = 0.857$$

$$n = 5.16\text{ins.} \quad a = 10.284\text{ins.} \quad d - n = 6.84\text{ins.}$$

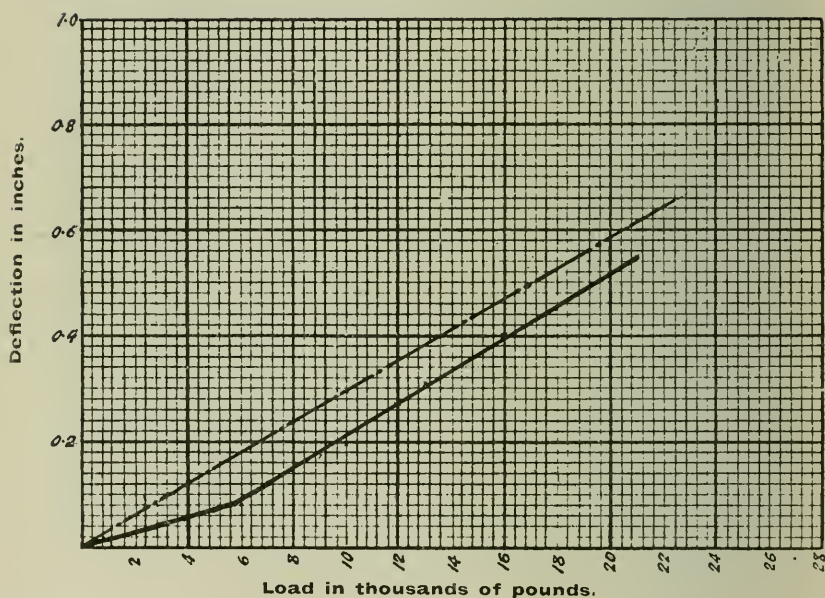


FIG. 4.

Beam No. 4. Talbot 1904 Experiments. Rectangular beam single reinforcement. Load at $\frac{1}{3}$ points.

$l=168\text{in.}$ $b=12\text{in.}$ $d=12\text{in.}$ $A_t=5\frac{1}{2}\text{in.}$ Kahn bars, net section $0.25\text{ sq. in. each}=1.25\text{ sq. in.}$ $r=\frac{1.25}{144}=0.87\%$ $n_r=.395$
 $a_r=.838.$ $n=4.75\text{in.}$ $a=10.05\text{in.}$ $d-n=7.25\text{in.}$

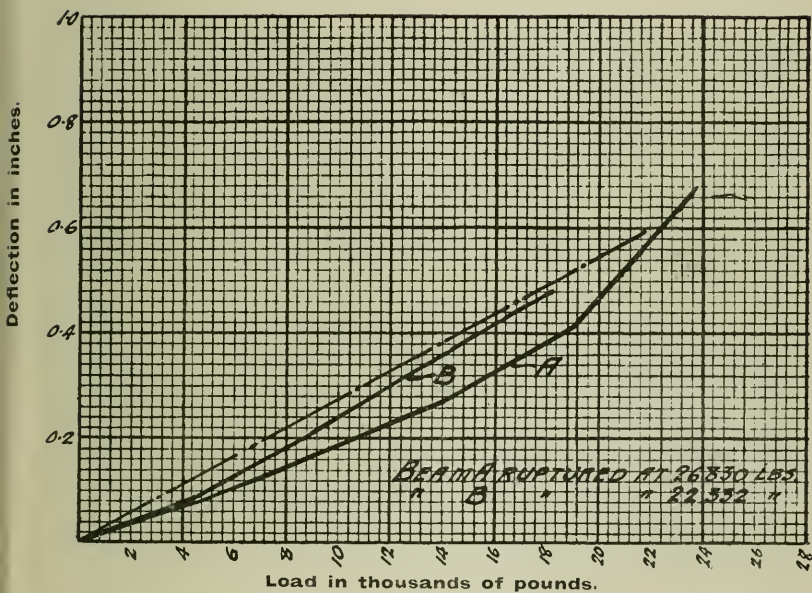


FIG. 5.

French Government Laboratory Tests of T beams, 1906.

$b = 40\text{in.}$ $d_s = 3\frac{3}{4}\text{in.}$ $d = 12.25\text{in.}$ $l = 196.875\text{in.}$

$A_t = 2\text{in.} \times \frac{1}{2}\text{in. bar} = 1\text{ sq. in.}$ $r = \frac{1}{490} = 0.00204$

$n_r = 0.22$. Neutral axis within slab. Load distributed. Beam A with riveted shear members inclined at 45deg. Beam B with loose ditto vertical. Position of reinforcement not exactly fixed.

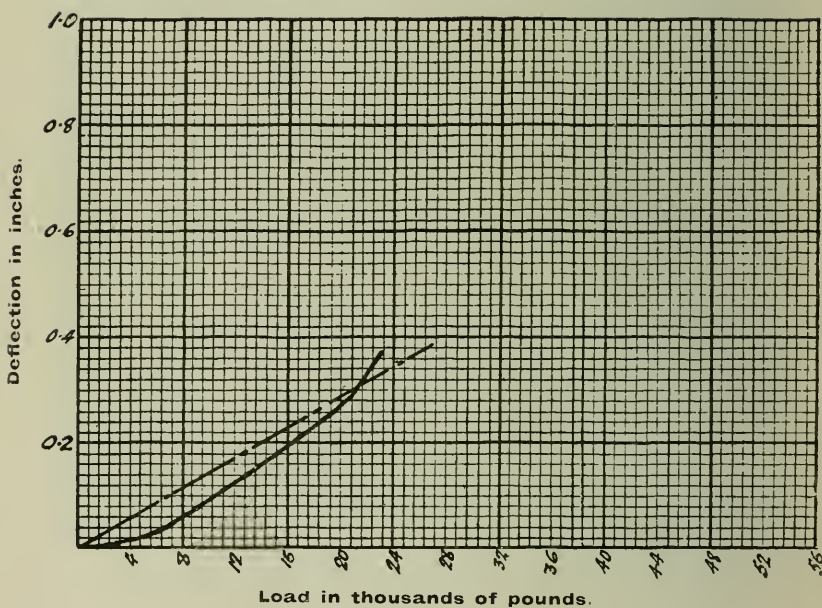


FIG. 6.

Kirkaldy Test Perfector beams 1911 (*Architects' and Builders' Journal*, 19th July, 1911). Single reinforced rectangular beams.

Span 120in. Total length 132in. $b = 7.15$ in. $d = 12.25$ in.

A_s two $\frac{3}{4}$ in. Perfector bars 0.44 sq. in. ea. = 0.88 sq. ins.

Shear reinforcement $\frac{3}{4}$ in. $\times$ $\frac{1}{8}$ in. at 8in. centres.

Load at $\frac{1}{3}$ points. Mean of 3 tests. 4-2-1 concrete.

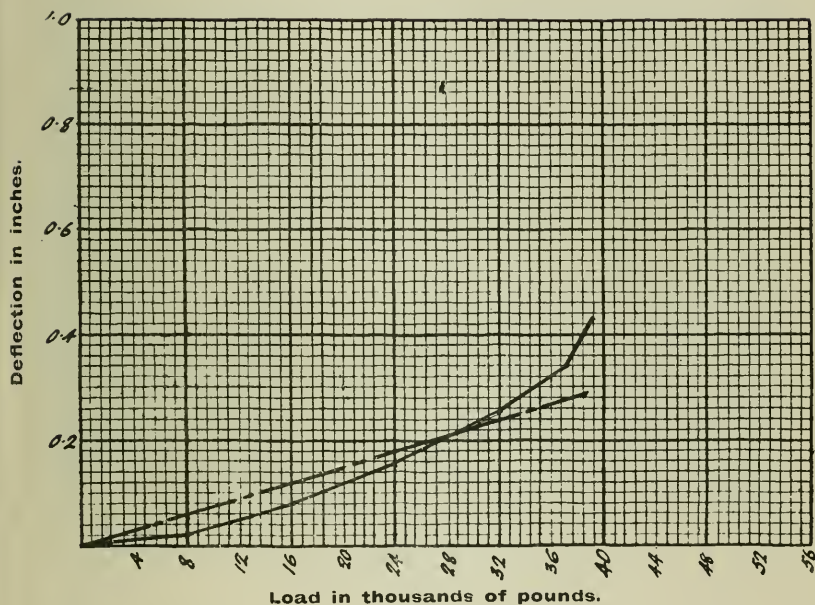


FIG. 7.

Kirkaldy Test Perfector beams 1911 (*Architects' and Builders' Journal*, 19th July, 1911).

Single reinforced T beams.

Total length 132in, Span 126in. $b=35.8$ in. $d=12.12$ in
 $br=7.2$ $ds=4.08$ ins. A_t two 1in. Perfector bars $=1.56$ sq. ins.

Shear reinforcements 1in. $\times \frac{1}{8}$ in. stirrups zigzag 8in. centres.

Slab reinforced transversely with $\frac{3}{8}$ in. diameter rods straight and curved 5in. centres.

Load at $\frac{1}{3}$ points. Mean of 3 tests. 4-2-1 concrete.

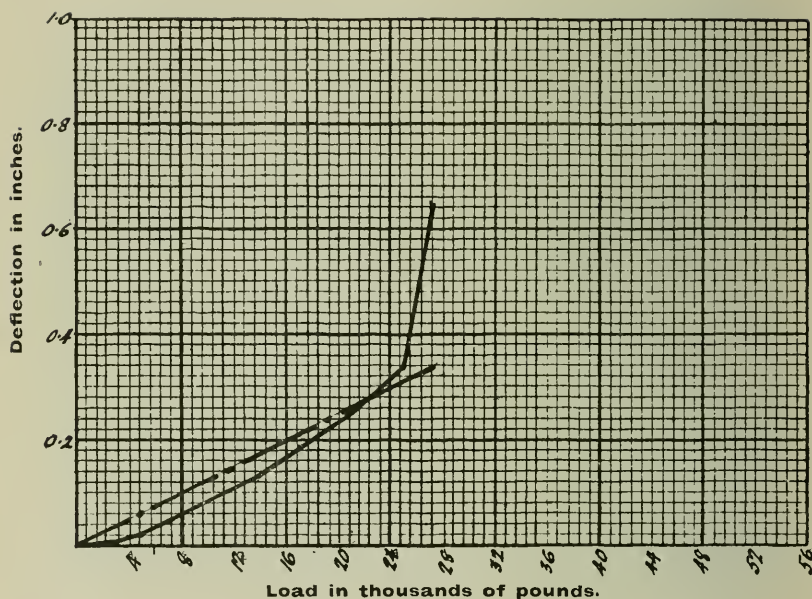


FIG. 8.

Kirkaldy Test Perfector beams 1911. (*Architects' and Builders' Journal*, 19th July, 1912).

Double reinforced rectangular beams—

Span 120in. Total length 130in. $b = 7.24$ in. $d = 11.72$ in.

A_t two $\frac{7}{8}$ in. Perfector bars = 1.20 sq. in.

A_c one $\frac{3}{4}$ in. Perfector bars = 0.44 sq. in.

Shear reinforcement $\frac{3}{4}$ in. $\times$ $\frac{1}{8}$ in. stirrups 4in. apart up to 3ft. 4in. from bearings 8in. apart in centre.

d_c assumed to be same at top as at bottom of beam = 14.09
 $-11.72 = 2.37$ in. $d_{ct} = \frac{2.37}{11.72} = 0.213$ $r = \frac{1.2}{7.4 \times 11.72} = .0138$

Load at $\frac{1}{3}$ points. Mean of 3 tests. 4-2-1 concrete.

DISCUSSION.

Mr. E. F. Etchells thanked the President for according him the honour of opening the discussion. He did so with peculiar pleasure for several reasons. One was connected with the table of notation on the first page of the paper. He had lately been looking into the history of standard algebraical notation starting from the year 3500 B.C. The earliest trace of it in this country appeared to be a paper read in 1884 before the Institution of Electrical Engineers. The first body to take up the question of a rational notation for structural engineering was the Civil and Mechanical Engineers' Society, who took it up about January, 1908, and since then it had been taken up by other institutions. It seemed a curious coincidence that two societies which now met in that building were the two selfsame societies which first took up the question of standard notation in this country ; each independently of the other.

The last paragraph on p. 312 stated : " It does not require much detailed investigation to appreciate that the fibre stress of 600 lb. per sq. in., which is the limit of good concrete in compression in beams, obviously cannot produce deformations comparable with those which result from 11 or 12 cwts. per sq. in. on timber, or $7\frac{1}{2}$ tons per sq. in. on steel." He had worked out the three cases with the following results :—

Material.	Tensile Elastic Modulus. E.	Permissible Tensile Stress <i>t</i> .	Elongation of a Piece originally 1,000 ins. long. <i>e</i> .
Fir 	lb. per sq. in. 1,700,000	lb. per sq. in. 1,344 (12 cwts.)	in. 0·79
Mild Steel 	30,000,000	16,000	0·53
Concrete [1 : 2 : 4] ...	2,000,000	600	0·30

While he believed they were comparable, the author was quite right in his contention that the concrete was least extensible, and should have the least admissible deflection.

On p. 314 the author said : " The Regulations in their present form appeared to have been carefully compiled from codes already in existence in Europe and America." This was true. The work was carefully compiled, and not only was every known code examined, but also every text-book in the language.

It was more than a compilation. He believed that the data which the Council had gathered were only the bricks on which

the structure was based. The author had showed in his paper how a brick or two here and there might be changed.

The author was right as to the inadequacy of existing data on deflection. They were very scanty, and, if one built up a scientific theory, it would not be readily understood by builders generally. They had to deal with a building code rather than a scientific treatise, or a simple guide-book for the man in the street. Sometimes the regulations might appear to be too definite, and at other times too abstruse, but the endeavour was always to steer an even course between the two extremes. That middle course had naturally been blamed by both sides.

He thought that the author had fallen into error in the last paragraph on p. 314, where it was stated that the clauses determining the strength of pillars were based on a mistaken application of Euler's formula. This was evidently written under the impression that the draft regulations had unintentionally applied to all pillars a rule which Euler intended to apply only to pillars of great length; but he (the speaker) wished to say that there was no misapplication of the above formula.

Four distinct assertions were made. The first was that the French Code was based on a mistaken application of Euler's formula. To controvert that he proposed to read from a translation of the French Code which he had recently made. He had retained to some extent the idiomatic French so as to keep close to the original

"To make sure (*pour s'assurer*), to assure oneself against the crippling of compression members they can make use of the rule of Rankine, which is translated by the following inequality:—

$$\frac{N}{\Omega} \left(1 + \frac{\kappa l^2}{10,000 r^2} \right) < R_6$$

where κ is a numerical co-efficient depending on the conditions to which the piece is submitted at its extremities

[NOTE BY THE TRANSLATOR.

A more English form of the above relationship would be:—

$$\frac{P}{A} = \frac{u}{1 + \frac{\kappa}{10,000} \left(\frac{l}{g} \right)^2} \text{ where}$$

A = Area in sq. in.

P = Total Pressure in lb. on the pillar.

u = ultimate compressive resistance of the material in lb. per sq. in.

l = length in inches.

g = gyration radius in inches.

κ = a constant depending upon the end conditions.]

The French report proceeded :—"When the compressed member is of great length it will be found that unity is negligible in comparison with the expression involving κ and the ratio of length to least radius of gyration. The inequality which expresses the condition of stability can then be put under a simplified form *which is the formula of Euler*, with a safety factor equal to 4. It is seen, then, that the indications furnished by that formula accord with those of Rankine's rule for *pillars of great length*."

The next statement was that the R.I.B.A. report was based on a mistaken application of Euler's formula. To controvert this he would point out that the R.I.B.A. report did not discuss Euler's formula at all, and did not even refer to it.

The 1911 Report, page 20, states that "For pillars more than 18 diameters in length there is a lateral buckling of the pillar as a whole. The strength of such pillars would be best calculated by *Gordon's* formula, but there are no experiments on long pillars by which to test the values of the constants for a concrete, or concrete and steel, pillar.

"There does not seem, however, to be any probability of serious error if the total load is reduced in a proportion inferred from *Gordon's* formula to allow for the risk of buckling."

The third statement was that the L.C.C. had made a mistaken application. This also could be shown not to be the case. He could not particularise here, but there was in the technical libraries of the various technical institutions printed information (written both by officers of the building authority and by officials of the Government Department which dealt with the regulations), and those books, articles and papers would show that such misapprehensions never could occur.

Moreover, Mr. Noble Twelvetrees, a former President of the Civil and Mechanical Engineers' Society, writing in 1900, twelve years ago, made it very clear that Euler's formula was only for long slender pillars; besides which, Leonard Euler himself was born at Basle in the year 1707, about 205 years ago, and his work had been translated into practically every language. Engineers had been for 200 years explaining what Euler really intended, and he (the speaker) did not think that so long after Euler's time they were likely to make a mistake as to what he really did mean or unconsciously to misapply his formula.

The author stated that they had departed from Euler's formula, but perhaps a certain modification might have been adopted *faute de mieux*, as the French report would say. He (the speaker) held that this might be entirely justifiable.

The disastrous collapse of a gasholder which occurred in Hamburg in December, 1909, had created a considerable stir among German engineers. The accident killed thirteen people

at once and injured forty-seven, some so severely that seven more died. A judicial inquiry was opened, and the contractors were proceeded against; but the Public Prosecutor finally withdrew his charge on the strength of the expert evidence. The several experts agreed that the cause of the accident was not an explosion nor any other special elementary phenomenon. They unanimously ascribed the collapse to insufficient strength of the structure. They did not hold the contractors responsible, however, because the contractors had merely done what was fairly common practice—that is, applied Euler's column formula without restrictions. Euler's formula was not so applied in our country, nor was its unrestricted use sanctioned by most German engineers. But it would appear that the rules drawn up by German authorities did not sufficiently specify the conditions under which Euler's formula might be applied. The experts were hence inclined to exonerate the contractors, and the proceedings were abandoned. (*Vide Engineering*, 30th June, 1911.)

Having regard to the whole of these facts, they might, he thought, take it that there had not necessarily been a misapplication. It was possible, however, that any stringency could be obviated without increasing the danger, and a way might be found in a suggestion he had heard publicly made at another place.

There was a further statement at the foot of p. 314 to the effect that the specified limit deflection would appear to be positively dangerous. Without any further qualification as to the type of beam and the stress it might appear to be so, but later clauses limited the stresses, both for the normal load and the test load, and these stresses were within safe limits. Many of the clauses of the regulations would be held to be imperfect if they were isolated.

On p. 315 the author said: "No beam or floor of ordinary proportions could ever show such a degree of deflection. It would simply cease to exist." Again, it would be found that safety was assured in all cases by the limitations of stress, and the deflection clauses as drafted permitted of the normal deflections of cantilevers and beams of concrete stronger than 1:2:4.

He did not think that they would find the regulations dangerous, however, but probably the deflection clauses could be amplified and extended to meet each case with greater exactness, but it was hoped that the consequential greater complexity would not call forth an appeal for the former simplicity when it was too late. It would be found that a deflection of $\frac{1}{800}$ would give a stress of 600 lb. on the extreme edge of the concrete with the ends freely supported, the load uniformly distributed, and 1 to 4 concrete. Incidentally the $\frac{1}{800}$ happened to be midway between $\frac{1}{600}$ and $\frac{1}{1000}$.

He quite agreed with the author's statement that "It would obviously be better to have a standard criterion of deflection applicable direct to the fixed ends customary in reinforced concrete beams."

As regarded "the thankless field of active legislation," he could not agree with the author, because he believed that the builders in London, the building authority, and the Government Department would be grateful to anyone who would help to make the regulations more useful and better for the builders, and to give safe, sound, and simple construction. The work was not thankless. The thanks might not necessarily be voiced, but they were present all the same.

The author spoke convincingly when he said that the "British engineer requires to be personally assured of the accuracy of his calculations, and when the R.I.B.A. report tells him that the moment of resistance of a T beam is—

$$cbdd_s \frac{s_s^3 + 4mrs_s^2 - 12mrs_s + 12mr}{6(s_s^2 + 2mr)}$$

he prefers to use a rolled joist." He quite agreed, but it was pointed out that the R.I.B.A. report was intended to set down the scientifically exact basis as far as was reasonably practicable, and it was for the writers of text-books and the builders to find the approximate methods and the quicker ways which would be within the requirements of that report. This contention had been raised publicly on many occasions. The Building Authority were told that they ought not to give the short cuts because they often were approximations on the side of expensiveness. They were told it would be better for them to allow the scientific rule, and then the builder who did not know very much of his subject would take a short and ready approximation which was on the safe side, and the scientific man could come along and perhaps work to a greater nicety and a possibly slightly less safety factor. and the building owner would then get the advantage of the greater skill brought to bear on the particular design. That contention was no part of a doctrine of the building authority, but it had been put forward as a reason why the lengthy formulæ should be given. He did not necessarily agree or disagree. He referred to a contention put forward by others.

The paper was a very important one, and it would probably be referred to again at a later date in the negotiations which were still to take place. For that reason it was necessary that some agreement should be come to now so that there might be more of agreement at a later stage.

He would ask for the derivation of the formulæ on p. 319, which were all new and were dissimilar from the equations in the R.I.B.A. report and other documents. Some of them might be simplifications of the author's own working.

He would also ask whether any suggestion which might be made for a rule dealing with deflections should not also give the kind of concrete. Suppose the deflection be $\frac{1}{800}$ of the span for an extreme fibre stress of 600 lb. per sq. in., that was for a 1 to 4 concrete. If he had $1\frac{1}{2}$ to 3 the stress would go beyond 600 lb., and that would have its influence on the deflection. They were gradually adding to the number of factors, although it might be impossible to include them all in detail with exactness. For example, the conditions of storage of the cement would affect its elastic properties, and consequently have an effect on the deflection when it was made into a concrete beam.

Finally, he would like to thank the author for having written the paper, and to say that, personally, although it meant more controversy, he, nevertheless, welcomed any attempt to lay down a science of reinforced concrete and to make construction in reinforced concrete as scientific as in other materials. He had endeavoured for a long time to bring reinforced concrete properly into the field of scientific engineering. There was a time when it was outside that field, and was like astrology before astrology grew into astronomy, and like alchemy before alchemy grew into chemistry. Perhaps there would be a time when reinforced concrete would become a harmonious and integrant part of the wider science of structural engineering. He believed he could state that it had been the intention of all those who had had anything to do with the regulations to bring reinforced concrete into line with the other materials, and to judge it on the same basis and by the same laws, and not to have a special set of conditions with reference to it.

If he was in order he would propose a vote of thanks to the author of the paper.

Mr. E. Dru Drury seconded the vote of thanks. He said that it was a very illuminating paper and discussion to one placed as he was. He happened to be the District Surveyor of Westminster, where concrete construction was going on largely at the present time.

Mr. C. T. A. Hanssen said that the diagrams often given in text-books were beautiful, but they did not do away with theoretical calculations.

He was working with a German firm last year, and saw some ingenious designs, including one of a floor over the dining hall of an hotel, the hall being nearly 50ft. wide. It would, of course, have been possible to put in 3ft. girders, but floor space and cubic building space were valuable, and it was desired to avoid deep girders. Over the dining hall there were two rows of bedrooms, with a corridor between. The engineer of the company arranged the partition walls of the bedrooms with diagonal bracing, so that each wall formed the web of a girder. He thus got a number of

girders 12ft. deep, for which the ceiling of the dining room, properly reinforced with longitudinal rods, served as the lower flange and the ceilings of the bedrooms above the hall became the upper flange. The ceiling of the hall was therefore supported on girders 12ft. deep, thereby not only avoiding the necessity of using columns in the hall, but also saving very much space and material. Such results could not be obtained by men who depended merely upon tables, however useful they might otherwise be. By thoroughly mastering the theoretical principles engineers were often able in this manner to effect material reductions in the cost of ferro-concrete structures.

He thought that engineers should not seek to avoid scientific calculations too much, because great results could be obtained by the intelligent application of first principles instead of adhering too blindly to formulæ and tables.

Mr. E. P. Wells thought that the author in writing the paper had been guided very largely by experiments made in America and elsewhere on what he (the speaker) called poor concretes, that is to say, 6 to 1 mixtures. As a rule the formulæ relating to reinforced concrete had been largely based upon American tests. It was well known to those who were experimenting in concrete that for rich concretes—that is to say, 5 to 1 and 4 to 1—where one got an ultimate crushing resistance of anything from 300 to 600 tons per sq. ft. (and he had had results as high as 650 to 820 tons per sq. ft.) the formulæ applied to ordinary 6 to 1 concrete were absolutely useless.

With a concrete which gave such a high crushing resistance they had, in actual practice, in a beam a 6, 7, 8, or sometimes 20 to 1 factor of safety as against the ordinary 4 to 1 factor in the tension member. If they constructed a concrete beam, either rectangular or T-headed, where the factors of safety were the same in compression as in tension, then, if they loaded the beam even up to the calculated amount they would get a deflection of about $\frac{1}{800}$ to $\frac{1}{500}$ of the span. This he had obtained in actual practice. But where they had a factor of safety in the compression member of 8 or 10 to 1 the deflection became only about $\frac{1}{2000}$ and $\frac{1}{3000}$ and sometimes $\frac{1}{5000}$ of the span.

If they took a T-headed slab as the compression member it was almost impossible to say how far the stresses were going to extend. When the beam was under test—and as a rule only one beam was tested and not two—no one could calculate the deflection. He found, as a rule, where they had beams continuous over more than two points of support, that when they were loaded up there was no ordinary measurable deflection. With an instrument which could test to $\frac{1}{2000}$ of an inch, deflection could be detected easily. Anyone walking over the floor caused deflection, but such refinements in testing were very absurd. As a rule, with beams of

20ft. span, where the ratio of depth to span was about $\frac{1}{16}$ or $\frac{1}{20}$, it would be found that under normal conditions about one-sixteenth of an inch was the average deflection. He had found this as the result of many experiments. That was where the factor of safety in the compression member was greatly in excess of that in the tension member. But directly they began to balance the two it was a different matter altogether. The deflection was then very considerably increased.

Another consideration with reference to the deflection was the effect of low temperature upon concrete. Take, for example, a beam made on a cold day followed by two or three months of extremely cold weather, so that the temperature of the beam was often down to freezing point, or only a few degrees above. If they were to cut a cube out of the concrete from which the beam was made, it would be found that the compression would be about one-half or even less than half of the compression that would obtain in a laboratory under ordinary test conditions. There would then be a very low factor of safety both in tension and in compression. If the same beam were tested one week afterwards at a temperature of 60 deg. Fahr., then, owing to the rapid increase in the strength of the concrete during the short period of one week and a high temperature the result would be very different. Tests were generally made with test beams in laboratories and not under the normal conditions prevailing in the structure of an ordinary building. As an instance, on the previous Friday a floor had been put in, and the frost attacked it; the work had been cut out and broken up that morning, but when he went on the work later the foreman was mixing the old material with new cement, and said that he thought it was quite good enough. He would ask the author how calculations could apply to such a case.

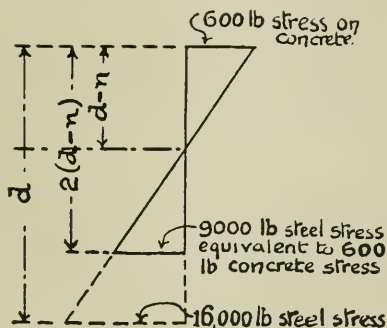
The strength of steel was practically a constant, but the concrete increased in strength from the day it was made up to seven or ten years. How was it possible to get a formula which would be anywhere near correct in such a case? As his friend Mr. Etchells knew, he was always dead against elaborate formulæ for reinforced concrete in view of the uncertain condition of the concrete. Even when it was put into the work nobody could say that it was going to crush at 100 or 400 tons per sq. ft. unless experiments were made with cubes at the time of laying and from the material being put in. It was necessary to make a laboratory test and an *in situ* test, subjecting the concrete cubes to the same conditions as in the building, viz., exposure to air and varying conditions of weather.

Even if all these points were known, no formula could be applied to find the actual deflection which would take place in a beam. In the matter of reinforced concrete, if people were to

apply a little more common sense and less mathematics it would be better for the profession.

He would not have made these remarks with reference to concrete unless he had made so very many experiments, many thousands in all, extending over the last fourteen years. His conclusion was that anyone who set forth a hard and fast formula did not know what he was talking about. After all the experiments that he had made, he knew but little more about concrete than when he first started.

Mr. C. Glenday thought there was a mistake in the formula on p. 315. Following the formula for deflection on p. 313 was the statement: "For girders of uniform section under distributed load the constant k is $\frac{5}{24}$." On p. 315 the constant had been assumed as $\frac{5}{24}$, but he scarcely thought that that was justifiable, because, as a matter of fact, it would only be $\frac{5}{24}$ in the event of the stress in the steel being 9,000 lb. per sq. in., which stress on the steel gave the same strain as 600 lb. per sq. in. on the concrete.



Referring to the diagram, if the stress per sq. in. on the concrete were 600 lb., then, to obtain conditions equivalent to those referred to by the Author on p. 313, it would be necessary to get a stress on the steel corresponding to 600 lb. concrete stress (i.e., $600 \times 15 = 9,000$ lb. per sq. in.) which gave a stress diagram with the neutral axis in the centre of the beam.

Referring to the beam analysed on p. 315, and taking 16,000 lb. as the steel stress, it would be necessary to extend the diagram as shown. The effect would be that to apply the formula and the constant on p. 313 to the case under consideration they must take for d not the depth of the beam, but $2(d-n)$, and this, if applied to a beam designed for the usual stress ratio of $\frac{9000}{16000}$, worked out at $0.72d$. If this correction were applied to the formula, the stress on the concrete would be 480 lb. per sq. in., and not 666 lb. as stated.

One need not use mathematics to find that the deflection depended as much on the amount of steel as on the concrete. Take, for example, two concrete beams 5in. square, one reinforced with $\frac{3}{16}$ in. rods in the lower flange, and the other with the same number of $\frac{3}{4}$ in. rods. With both these beams uniformly loaded to give a stress on the concrete of 600 lb. per sq. in., it was obvious that the steel in the beam reinforced with $\frac{3}{16}$ in. rods was much more highly stressed than the steel in the beam with the $\frac{3}{4}$ in. rods. That meant that the lower flange of the beam with the $\frac{3}{16}$ in. rods had stretched more than that of the beam with the $\frac{3}{4}$ in. rods, and hence must have deflected more.

Mr. E. F. Etchells said that with regard to the statement of the last speaker that the deflection had not taken any account at all of the stresses in the steel, it would be interesting to notice that when account was taken of the stresses in the steel, the amount of deflection came out the same under similar conditions. Mr. Eli White, in *The Engineering Record* for 9th November, 1907, gave the means of calculating the deflection of steel beams on an assumption complementary to that of the author. The author had taken the area of concrete and turned that into an equivalent area of steel. The American method was to take the area of the steel in the bottom flange and convert the top flange of concrete into an equivalent flange of steel.

REPLY.

Mr. Percy J. Waldram, replying to the discussion, said, with regard to his statement as to the mistaken application of Euler's formula, that when the reinforced concrete Regulations came out in their final form it would be known whether the original formula was correct or not. He certainly thought that the wording of Clause 67 was a mistaken one. It applied Euler's formula or Gordon's formula (both of which were similar) to all columns. He made the suggestion in *Engineering* of April 5th last that the clause should be altered into relative lengths. If that suggestion were adopted there would be no great harm done.

Mr. Etchells had suggested that the French code was not based on a mistaken application of Euler's formula. He (the author) had not read the whole of the French report in the original French, but only in an abbreviated English translation. Perhaps he had not given the French authorities credit for having noted that the clause which appeared in the code was to a certain extent inconsistent, but he believed that nobody had ascertained that Clause 87 of the regulations, as printed in the Council's Minutes, would be quite unworkable unless it were expressed in terms of relative lengths.

With reference to the suggestion made by Mr. Etchells that $\frac{1}{800}$ should be taken instead of $\frac{1}{8000}$, that might possibly be a

compromise at the end, but if engineers were going to stipulate for a test deflection they ought to know what they were stipulating for, instead of making a general rule applicable to all kinds of things. It might be absolutely impossible to say what strength concrete would have at a certain age, but, when an official code made a statement, it was certainly desirable that that statement should be such that it could not lead to any possible misconceptions in the future. It might be difficult to ascertain the difference of deflection due to conditions of fixed ends, but, if the code stipulated for a certain deflection, that deflection should certainly be one about which something was known.

Mr. Wells' remark that a person who suggested any formula for deflection did not know what he was talking about, he would leave to the meeting. Possibly the suggestion was correct, but it applied equally to the compilers of the reinforced concrete Regulations of the London County Council. They certainly left the matter in a fog, making a general statement that all beams under test should show one deflection, without specifying the proportions of the beam, the conditions of end fixing, or the method of loading.

Mr. Etchells said that the test put forward was only for the purpose of ascertaining when a thing was dangerous, and the niceties of deflection were really beside the point when a structure was obviously in a dangerous state. The President of the Concrete Institute could give instance after instance where the dangerous condition of a structure was measured, not in eight-hundredths or thousandths of an inch, but in inches.

Mr. Wells said that when the question of deflection arose he wanted to get it fixed at about $\frac{1}{1500}$ to $\frac{1}{1000}$ of an inch. It was originally taken at $\frac{1}{800}$, and was afterwards altered so as to admit of work which personally he would not pass. He would like to see the deflection at about $\frac{1}{2000}$. An engineer would know then that there would be no possible danger if he loaded the structure up to three times the amount it was designed for.

Mr. Waldram, continuing his reply, said that if it was not desirable to investigate deflection at all, he was sorry to have taken up so much time. Yet when there was a standard placed before engineers, and when they had to look forward to a time when they would have to submit their buildings to certain test deflections, it was certainly desirable that they should know as much as possible about the difference between calculated and actual deflection. He thought he might fairly claim to have taken, at any rate, some of the existing data of actual deflection, and to have shown what was the deflection implied by the ordinary standard formulæ. If engineers used a certain formula

for strength and certain moduli of elasticity they implied a certain deflection. The formula might or might not be correct. If it were correct the calculated would equal the actual deflection. When engineers used the standard formula for strength they implied a straight line deflection. That was admittedly incorrect, and the difference between the actual and calculated deflection at different loads showed the extent of the error in the standard formulæ. It might be, as Mr. Wells suggested, that the time he had spent in trying to show a practical and easy method of ascertaining the difference between the deflection implicated by the standard formula and the deflection which actually took place had been wasted, but he did not think so. Engineers could not possibly know too much about the subject.

He had expected that the suggestion he had made that reinforced concrete was weaker than steel or fir would have raised a discussion. He was almost sorry to see that it was accepted so tacitly.

Mr. Etchells had questioned the formula for T beams as not being exactly in the form given in the R.I.B.A. report. It was in the more convenient form given in the Regulations, but adapted to the R.I.B.A. conditions.

With reference to the factors governing deflection, Mr. Wells had suggested that the increasing strength of the concrete was a factor which made any investigation of the subject useless, but if a test deflection was stipulated for by any responsible authority, the kind of concrete could be specified, and the date at which the test was made should also be taken into account.

Mr. Etchells had asked for the derivation of all the formulæ on p. 319, but he was afraid that he could hardly do that in the time at his disposal. He hoped that the derivations would be published at an early date.

Mr. Hanssen had mentioned the uselessness of diagrams and text-books. Possibly Mr. Hanssen's opinion was due to the fact that one frequently got two or more diagrams which saved a lot of time, and then one found that many points, involving a considerable amount of labour, were not given; but it was possible even for an elementary student to take all the formulæ and apply them.

The example which Mr. Hanssen gave of an upper floor being used to support the ceiling of a large room was excellent. One of the drawbacks of reinforced concrete was the necessity for considerable depth, for which space was not always available; and it was very necessary for a designer of reinforced concrete to look out for any adventitious aids to increasing the depth of his members, such as had been mentioned. Reinforced concrete lent itself readily to such construction as that where the whole of the partitions of one floor could be utilised to strengthen an exceptionally large span over the floor below.

The accuracy of the formula on p. 315 had been questioned by Mr. Glenday, but he had overlooked the fact that on p. 313 it was stated that the term d was either the depth in symmetrical sections or (in unsymmetrical sections) twice the distance between the neutral axis and the layer of fibres.

In cases where the deflection would not be affected by the concrete in tension the ratio of length to depth should be the ratio of the length to twice the distance of the fibre from the neutral axis. In doubly reinforced beams there would be very little difference because in those beams the neutral axis was generally much nearer half the actual depth.

Mr. Wells had asked how it was possible to get any formula for deflection which would allow for the increasing strength of the concrete. Of course, no one would suggest that it was possible to get any formula for increase of strength, but the corresponding increase in stiffness could be allowed for.

All the formulæ purported to do was to show the theoretical deflection which was indicated by the theoretical straight line formula. Engineers knew that the theoretical straight line formula was not correct, but still they used it. It was just as well that they should know what deflection was indicated by it. It was quite possible, if one knew the difference in the modulus of elasticity which was indicated by varying differences of strength, to ascertain what the theoretical deflection would be with varying increases in age.

Mr. Wells' reference to the action of temperature was extremely interesting. A beam, however, would scarcely be tested in a frozen condition, more especially because it would be customary in carrying out the regulations to keep test cubes of concrete and test them in similar conditions to the concrete in the building. During the time that the cubes were frozen it would hardly be possible that the concrete would be tested for deflection, especially as, owing, he believed, to the information which had been given to engineers by Mr. Wells, the effect of freezing on concrete was now well known.

Mr. Etchells had referred to Mr. Eli White's formula, with which he (the author) was quite well acquainted before devising the formula in the paper. It was interesting to hear that the two formulæ gave identical results. Anyone endeavouring to use Mr. White's formulæ would, he thought, find it very tedious. That formula was, he thought, the first attempt ever made to get a theoretical formula for deflection showing what the straight-line formula really did indicate. As such it was exceptionally valuable, but it was too unhandy for ordinary use in the office. Even if the calculation for deflection was useless in every other way it certainly was useful if the draughtsman had to calculate the moment of inertia from both sides of the beam. This

operation could be done in a few moments, but the calculation would show immediately if there was a mistake.

Mr. Wells had referred to the extremely high stresses which could be got on very rich concretes, but he (the speaker) did not think that they had much bearing upon the present subject, because extremely rich concretes meant very expensive buildings and somewhat ideal conditions. He did not suppose that in the buildings of the future there would be any concrete very much richer than 4 : 2 : 1, or that they would get very much higher stresses in beams than were indicated in the regulations. The use of richer concretes for columns was another matter.

He was sorry to have conveyed the impression that he was trying to make the mathematics of the subject a little longer. His only object had been to try to make them shorter. In any case it certainly was better, even if they were going to have shorter methods eventually, to have some method of investigating deflection to start with.

ANNUAL GENERAL MEETING.

The Third Annual General Meeting of the Society was held at 17, Victoria Street, Westminster, on Monday, December 9th, 1912, the President, Mr. John Kennedy, being in the chair.

The Secretary read the report of the Scrutineers on the result of the postal ballot for the election of Council and Officers for 1913, and announced the awards of premiums made in respect of papers published in the JOURNAL during 1912 (see page 345).

The Report of the Council was read and adopted (see next page).

Messrs. W. B. Keen & Co. were re-elected as Auditors for the ensuing year.

A vote of thanks to the Council and Officers for 1912 was proposed, seconded, and carried unanimously.

A vote of thanks was passed to the Scrutineers, MM. A. T. Bean and Matthew Mawson for their services in connection with the ballot for the election of the Council for 1913.

REPORT OF THE COUNCIL FOR THE YEAR 1912.

Your Council, in bringing before you the customary review of the work of the Society during 1912—the third year since the amalgamation—are not able to record an increase in the number of members, but submit that in other respects satisfactory progress has been made.

In the early part of the year the Right Hon. Viscount Kitchener, K.P., G.C.B., O.M., G.C.S.I., G.C.M.G., G.C.I.E., D.C.L., LL.D., and Sir James A. Ewing, K.C.B., M.A., LL.D., F.R.S., accepted the invitations extended to them by the Council to become Honorary Fellows of the Society.

The Council have heard with regret of the deaths of the following corporate members :—

Fellows : E. Ault, F. G. S. Ham, T. J. Orme.

Members : W. J. Conn, J. T. Hurst, C. J. Light.

The membership roll of the Society at the date of issuing this report is as follows :—

Hon. Fellows, 25 ; Fellows, 65 ; Members, 340 ; Associate Members, 173 ; Associates, 10 ; total, 613.

FINANCE.

The accounts for 1912 will be made up and audited by chartered accountants early in the New Year, and copies will be sent to all corporate members. The Income and Expenditure Account for the year ended December 31st, 1911, shewed an excess of expenditure over income of £92 6s. 2d. due principally to very drastic writing down of assets and the fact that two dinners, instead of one, were held in 1911, when it was thought better to hold the Annual Dinner during the President's year of office rather than after its close, the result being that in that year one dinner was held in January and another in May. Taking together the two years 1910 and 1911, which included the expenses due to the amalgamation and incorporation, the total deficit was only £27 3s. 10d.

The investments have been increased during the year by the purchase of £300 worth of $3\frac{1}{2}\%$ India Stock.

FELLOWSHIP EXAMINATION.

The Examinations Committee, which was appointed in 1910 to deal with the arrangements for the Fellowship Examination, was reconstituted in March, 1912, as the Board of Examiners,

the Superintending Examiner being Professor Henry Adams, and the Executive Committee of the Board consisting of those Examiners who are also members of the Council. The List of Examiners comprises the names of some eighty engineers of high standing. The meetings of the Board have been frequent, and the very considerable work involved in arranging the many details which must be settled before an examination can be held has been well advanced.

STATUS PRIZE.

A number of essays were submitted this year in competition for the Status Prize, the subject being, "How to Improve the Status of Engineers and Engineering, with Special Reference to Consulting Engineers." After careful consideration the Council decided that none of the essays was entirely worthy of the first prize, which was therefore withheld. The second prize, of the value of £4 4s., was awarded to Mr. WILLIAM RANSOM, of Worcester, who will read his essay at a meeting to be held in April, 1913.

In 1913 essays will be invited on "A Scheme for the Registration of Engineers, including Particulars concerning the Registration of Engineers in British Colonies and Foreign Countries." The prize will take the form of books and instruments to the value of £10 10s. A copy of the regulations governing the competition can be obtained from the Secretary.

PREMIUMS.

The following Premiums have been awarded by the Council to the authors of papers read at meetings or published in the JOURNAL:—

The President's Gold Medal to Mr. W. P. DURTNALL for his paper on "The Generation and Electrical Transmission of Power for Marine Transportation."

The Bessemer Premium, value £5 5s., to Prof. HERBERT CHATLEY for his paper on "Resistance to Rolling."

The Clarke Premium, value £5 5s., to Mr. G. O. CASE for his paper on "Ligno-Concrete."

The Bernay's Premium, value £2 2s., to Mr. J. P. HARRIS for his paper on "The Construction of a London County Council Low Level Sewer from Battersea to Deptford."

A Society's Premium, value £2 2s., to Mr. P. J. WALDRAM for his paper on "Test Deflections in Reinforced Concrete."

PAPERS.

The Inaugural Address of the President, Mr. John Kennedy, was delivered on February 5th, 1912, and dealt with the subject of Marine Engineering, in which branch of the profession Mr. Kennedy has had a lifelong experience. The thanks of the

Society are due also to the following gentlemen, who have contributed papers read at meetings or published in the JOURNAL during 1912, but to whom Premiums have not been awarded :—

Mr. Henry C. Adams : " The Trolley Vehicle System of Rail-less Traction."

Mr. G. Noble Fell : " Rail Plateways."

Prof. F. H. Hummel : " The Modulus of Elasticity of Thin Flexible Strips."

Mr. Wm. Yorath Lewis : " Intermittency ; Its Effects in Limiting Electric traction for City and Suburban Passenger Transport."

Mr. Ernest R. Matthews : " Town Planning from an Engineering Aspect."

Mr. Spencer Sills : " The Subterranean Erosion of Water-bearing Strata in relation to Pollution."

JOURNAL.

The Council are desirous of extending the utility of the JOURNAL as a medium of information to individual members, and therefore they ask the members to offer suggestions for the introduction of new features or the improvement of existing ones. For instance, some engineers who have not the time to prepare a lengthy paper might occasionally send in reports of unusual circumstances that arise in the course of their practice, short accounts of new works, especially in the Colonies and abroad, brief descriptions of novel inventions, queries relating to difficult problems, and notes or comments on matters of current professional interest. The Editor will at all times be glad to consider contributions of this kind, and to give facilities for the publication of correspondence or inquiries that may be helpful to the members, for whose benefit the JOURNAL is produced.

The Council also invite the active co-operation of the members in preparing, or obtaining from their engineering friends, papers for publication and for discussion at the ordinary meetings. Members who reside abroad, and therefore cannot attend personally to read papers, have the opportunity of having their contributions published in the JOURNAL in the months of January, June, July, August and September (in which months no meetings are held), and papers published in this way rank equally with others for the premiums which the Council are able to award annually. Full instructions are available as to the manner in which papers are to be prepared, and a copy of these instructions should be obtained from the Secretary before a paper is written.

MEETINGS.

In addition to seven Ordinary Meetings of the Society, there have been eleven meetings of the Council and thirty-four meetings of the various Committees, including fourteen meetings of the Examination Committee and the Board of Examiners.

In order to preserve the continuity of the work and to relieve the President of some of his exacting duties, each Committee has now appointed a chairman, who is expected, as far as possible, to preside at every meeting of the Committee on which he serves, and thus ensure that the work of that Committee shall be carried on with due regard to what has previously been done.

THE LAW RELATING TO ENGINEERING.

The reprint of the lectures delivered by Mr. Costello in 1910-1911 has had an extensive sale during the year. There are still a few copies in stock, and a special discount is given to members of this Society who wish to purchase this very useful manual, which is a concise review of the legal position of the engineer in relation to clients, contractors, and others.

FREE LEGAL ADVICE.

During the year several members have availed themselves of the facilities which the Society offers for obtaining legal advice on professional matters. The thanks of the Society are due to the Hon. Solicitors, Messrs. Blyth, Dutton, Hartley & Blyth and Mr. R. H. Willcocks, LL.B., for their services in this matter, and in regard to other legal business which they have jointly performed at the request of the Council.

EMPLOYMENT REGISTER.

A number of vacancies have been filled by candidates whose names were on the Register. The Council invite Members to use the Register whenever occasion arises, and to make it known to their engineering friends who may be in need of assistants. All particulars may be obtained on application to the Secretary.

COUNCIL AND OFFICERS FOR 1913.

Messrs. A. T. Bean and M. Mawson, the scrutineers appointed to examine the ballot lists for the election of the Council and Officers of the Society for the coming year, presented their report to the Chairman at the Annual General Meeting, held on December 9th, 1912 (see page 343), the voting resulting in the election of the undermentioned gentlemen :—

President, ARTHUR VALON.

Vice-Presidents, H. C. H. SHENTON, NORMAN SCORGIE, T. E. BOWER.

Members of Council, HENRY ADAMS, C. T. WALROND, PERCY GRIFFITH, HENRY C. ADAMS, J. R. BELL, S. COWPER-COLES, H. P. MAYBURY, B. H. M. HEWETT, F. H. HUMMEL, G. A. BECKS.

Associate Member of Council, R. J. SIMPSON.

Hon. Secretary and Hon. Treasurer, D. B. BUTLER.

CONCLUSION.

The Council rely on your continued interest in the work of the Society, and invite you to assist them according to your opportunities by introducing new members, and by giving, as far as possible, active personal assistance in advancing the objects which the Society has in view.

17, VICTORIA STREET,
WESTMINSTER, S.W.

9th December, 1912.

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